LBNE in the Precision Era of Neutrino Oscillation: Status and Schedule – Getting There

Zelimir Djurcic
Argonne National Laboratory

Fermilab Intensity Frontier Seminar Series
October 2, 2014.

Neutrino Oscillations

-The three neutrino mixing:

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} Big & Big & Small? \\ Big & Big & Big \\ Big & Big & Big \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

θ_{12} measured from $P(\overset{(-)}{\nu}_e \rightarrow \overset{(-)}{\nu}_x)$ by reactor $\bar{\nu}_e$ and solar ν_e.

θ_{13} measured from $P(\bar{\nu}_e \rightarrow \bar{\nu}_e)$ by reactor $\bar{\nu}_e$.
θ_{13} and δ measured from $P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e)$ by accelerator ν_μ.

θ_{23} measured from $P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_\mu)$
By atmospheric ν_μ and accelerator ν_μ.

-Neutrino oscillation parameters:

MNSP matrix:	3 mixing angles: θ_{12}, θ_{23}, θ_{13}
	1 phase: δ => CP-violation in ν-sector
Mass differences:	2 mass difference scales: Δm^2_{12}, Δm^2_{23}.

Neutrino Oscillation Results

-Current understanding

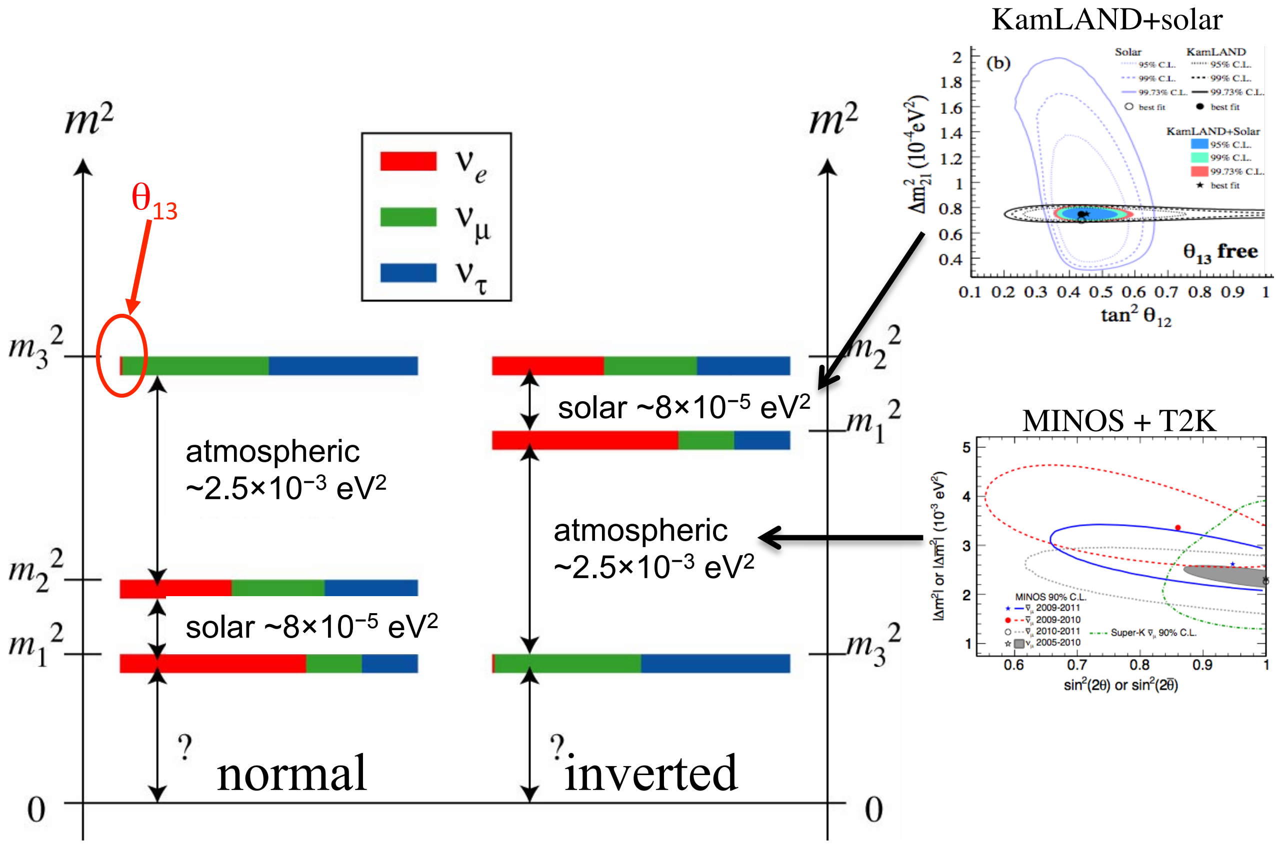
-Mass squared differences:

$\Delta m^2_{21} \sim 8\text{x}10^{-5}\text{eV}^2$
$|\Delta m^2_{32}| \approx |\Delta m^2_{31}| \sim 2.4 \text{ x } 10^{-3}\text{eV}^2$

-Mixing angles:

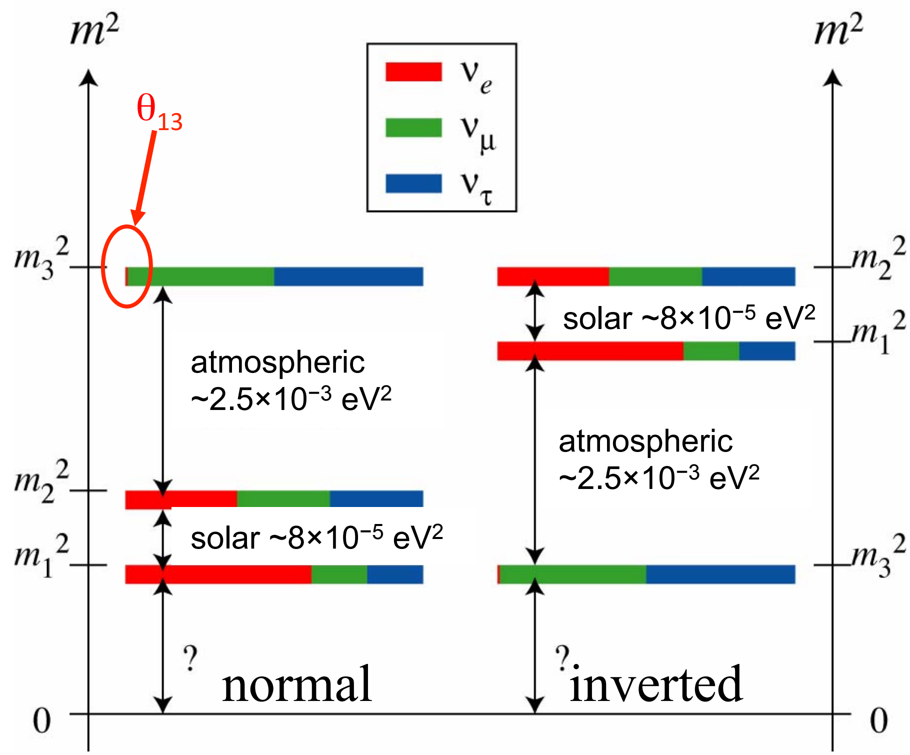
$\theta_{12} \sim 34^o$
$\theta_{23} \sim 45^o$
$\theta_{13} \sim 9^o$

-Absolute mass scale is unknown.



Neutrino Oscillation Questions

Recently measured what is ν_e component in the ν_3 mass eigenstate, i.e. θ_{13}.



Missing information in 3x3 mixing scheme:

1. Is the μ - τ mixing maximal?
   -Only know $\sin^2 2\theta_{23} > 0.90$.

2. What is the mass hierarchy?
   -Normal or inverted?

3. Do neutrinos exhibit CP violation, i.e. is $\delta_{CP} \neq 0$?

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = -16 s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23} \sin\delta \sin\left(\frac{\Delta m_{12}^2}{4E} L\right) \sin\left(\frac{\Delta m_{13}^2}{4E} L\right) \sin\left(\frac{\Delta m_{23}^2}{4E} L\right)$$

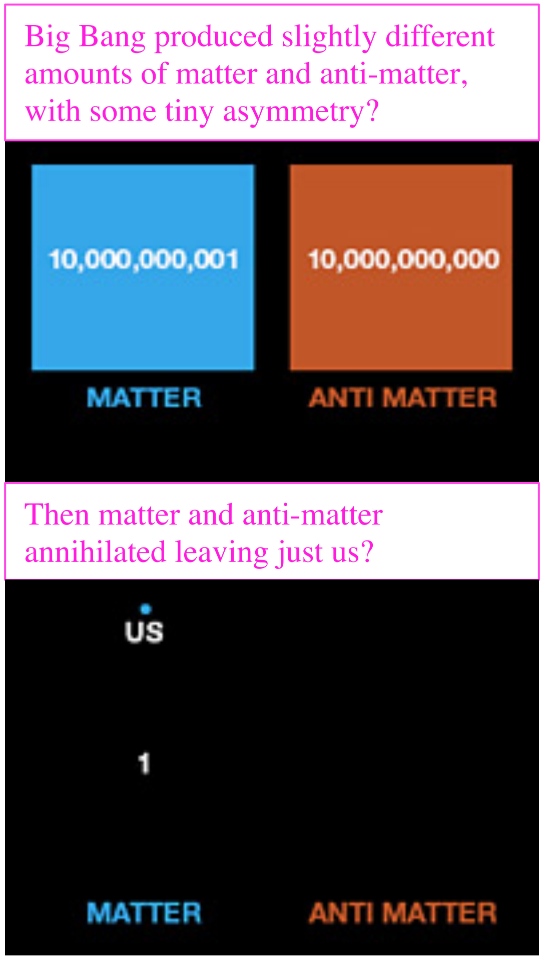
4. Why are quark and neutrino mixing matrices so different?

$$U_{MNSP} \sim \begin{pmatrix} Big & Big & Small \\ Big & Big & Big \\ Big & Big & Big \end{pmatrix} \quad \text{vs.} \quad V_{CKM} \sim \begin{pmatrix} 1 & Small & Small \\ Small & 1 & Small \\ Small & Small & 1 \end{pmatrix}$$

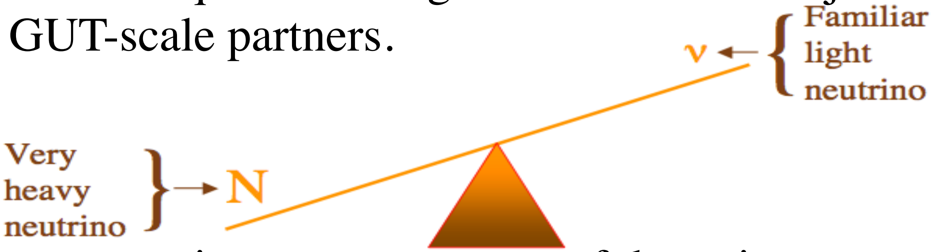
Why is CP-violation (i.e. $\delta_{CP} \neq 0$) with neutrinos so important?

-Striking feature of the Universe: only matter, virtually no anti-matter!

-Observation of CP-violation would make it more likely that the baryon-antibaryon asymmetry of the universe arose through leptogenesis.



-The theory of leptogenesis is linked to the see-saw theory and as a consequence the light neutrinos are Majorana and have GUT-scale partners.



-The matter-antimatter asymmetry of the universe may be explained through CP-violating decays of the heavy partners, producing a state with unequal numbers of Standard Model leptons and antileptons.

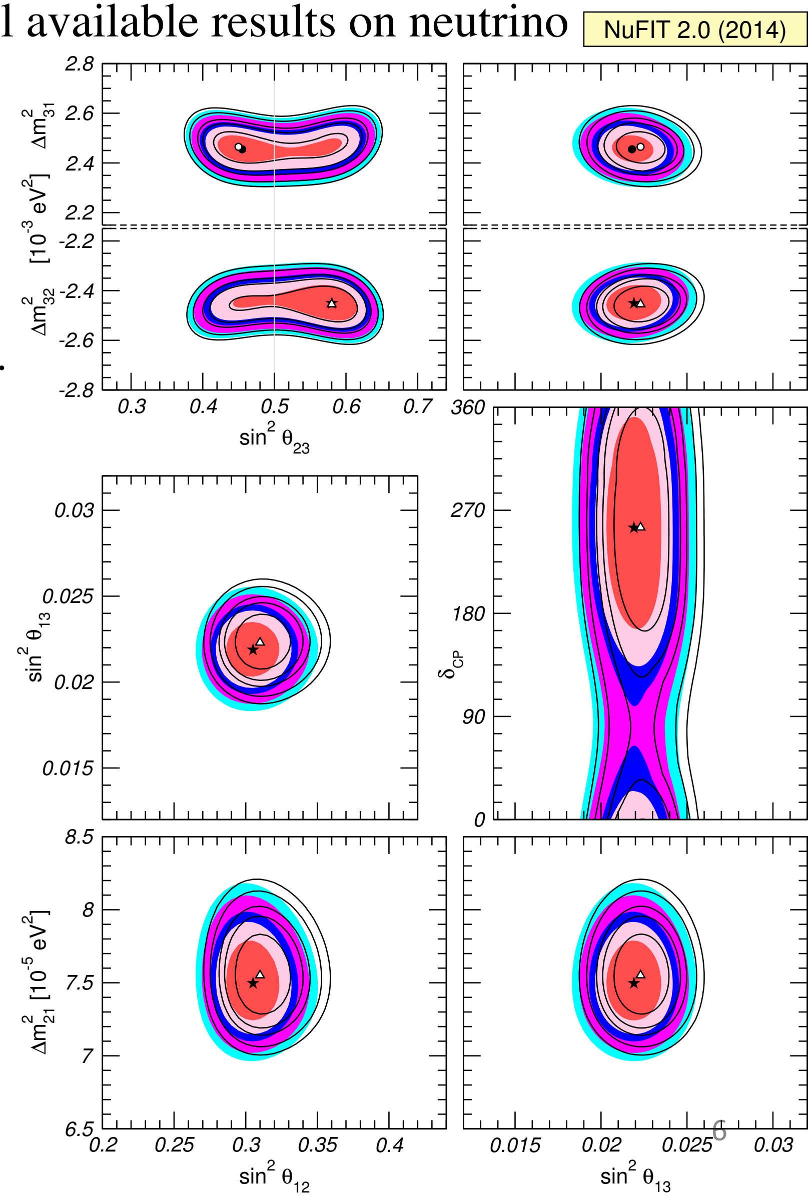
$N \rightarrow L^- + \varphi^+$ and $N \rightarrow L^+ + \varphi^-$ (φ^+, φ^- - Standard-Model Higgs)

-The Standard Model processes convert such a state into the world around us with an unequal number of baryons and antibaryons.

-It is thought that CP-violation would be very unlikely to appear in the heavy sector without happening in light neutrinos.

How well we know the oscillation parameters?

-To incorporate new knowledge on oscillation parameters into the three neutrino oscillation framework one usually performs global fits, where all available results on neutrino oscillation parameters are combined.



-Neutrino oscillation parameters:

MNSP matrix: 3 mixing angles: θ_{12}, θ_{23}, θ_{13}

1 phase: δ => CP-violation in ν-sector

Mass differences: 2 mass difference scales: Δm^2_{12}, Δm^2_{23}.

-Up-to-date results for the global fit to neutrino oscillation parameters from Gonzalez-Garcia, Maltoni and Schwetz (http://www.nu-fit.org).

How well we know the oscillation parameters?

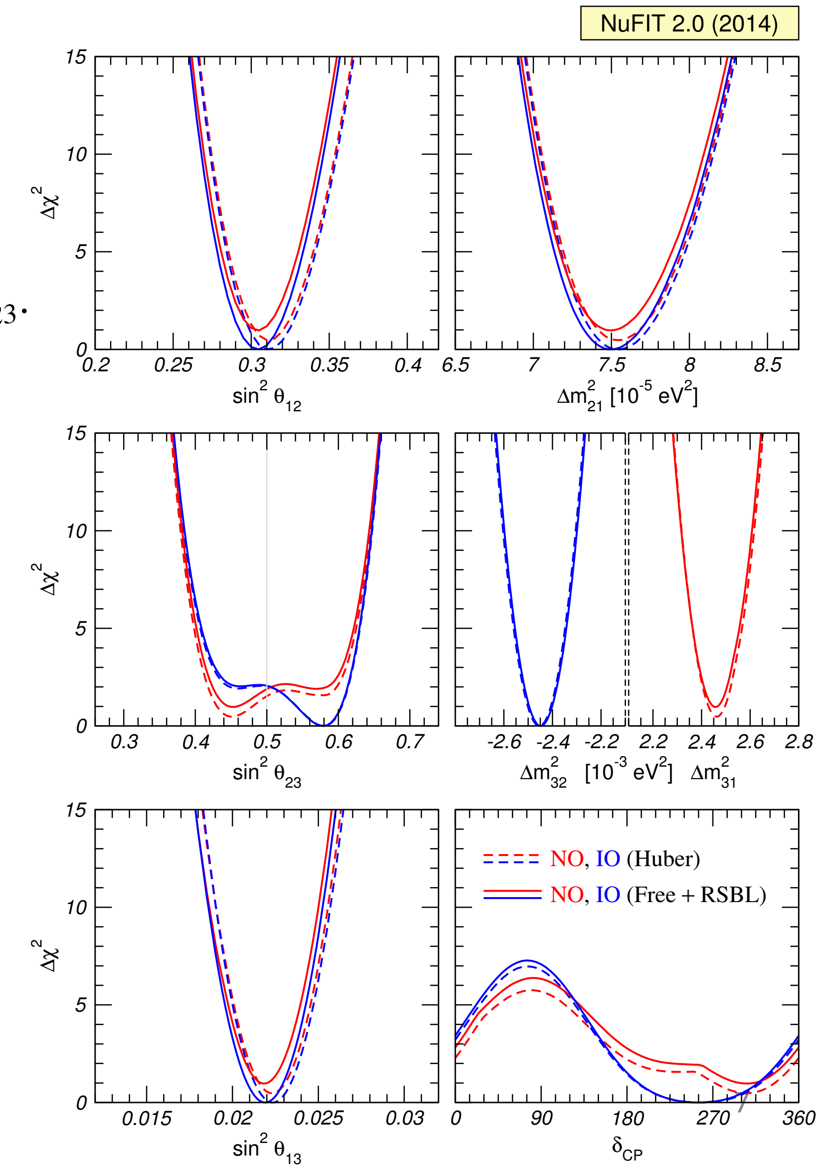
-To incorporate new knowledge on oscillation parameters into the three neutrino oscillation framework one usually performs global fits, where all available results on neutrino oscillation parameters are combined.

-Neutrino oscillation parameters:

MNSP matrix: 3 mixing angles: $\theta_{12}, \theta_{23}, \theta_{13}$

1 phase: δ => CP-violation in ν-sector

Mass differences: 2 mass difference scales: $\Delta m^2_{12}, \Delta m^2_{23}$.



-Up-to-date results for the global fit to neutrino oscillation parameters from Gonzalez-Garcia, Maltoni and Schwetz (http://www.nu-fit.org).

-How well we know the oscillation parameters?

How well we know the oscillation parameters?

NuFIT 2.0 (2014)

- Parameter ranges

	Normal Ordering ($\Delta\chi^2 = 0.97$)		Inverted Ordering (best fit)		Any Ordering
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range	3σ range
$\sin^2\theta_{12}$	$0.304^{+0.013}_{-0.012}$	$0.270 \to 0.344$	$0.304^{+0.013}_{-0.012}$	$0.270 \to 0.344$	$0.270 \to 0.344$
$\theta_{12}/^\circ$	$33.48^{+0.78}_{-0.75}$	$31.29 \to 35.91$	$33.48^{+0.78}_{-0.75}$	$31.29 \to 35.91$	$31.29 \to 35.91$
$\sin^2\theta_{23}$	$0.452^{+0.052}_{-0.028}$	$0.382 \to 0.643$	$0.579^{+0.025}_{-0.037}$	$0.389 \to 0.644$	$0.385 \to 0.644$
$\theta_{23}/^\circ$	$42.3^{+3.0}_{-1.6}$	$38.2 \to 53.3$	$49.5^{+1.5}_{-2.2}$	$38.6 \to 53.3$	$38.3 \to 53.3$
$\sin^2\theta_{13}$	$0.0218^{+0.0010}_{-0.0010}$	$0.0186 \to 0.0250$	$0.0219^{+0.0011}_{-0.0010}$	$0.0188 \to 0.0251$	$0.0188 \to 0.0251$
$\theta_{13}/^\circ$	$8.50^{+0.20}_{-0.21}$	$7.85 \to 9.10$	$8.51^{+0.20}_{-0.21}$	$7.87 \to 9.11$	$7.87 \to 9.11$
$\delta_{\mathrm{CP}}/^\circ$	306^{+39}_{-70}	$0 \to 360$	254^{+63}_{-62}	$0 \to 360$	$0 \to 360$
$\dfrac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.50^{+0.19}_{-0.17}$	$7.02 \to 8.09$	$7.50^{+0.19}_{-0.17}$	$7.02 \to 8.09$	$7.02 \to 8.09$
$\dfrac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$	$+2.457^{+0.047}_{-0.047}$	$+2.317 \to +2.607$	$-2.449^{+0.048}_{-0.047}$	$-2.590 \to -2.307$	$\begin{bmatrix} +2.325 \to +2.599 \\ -2.590 \to -2.307 \end{bmatrix}$

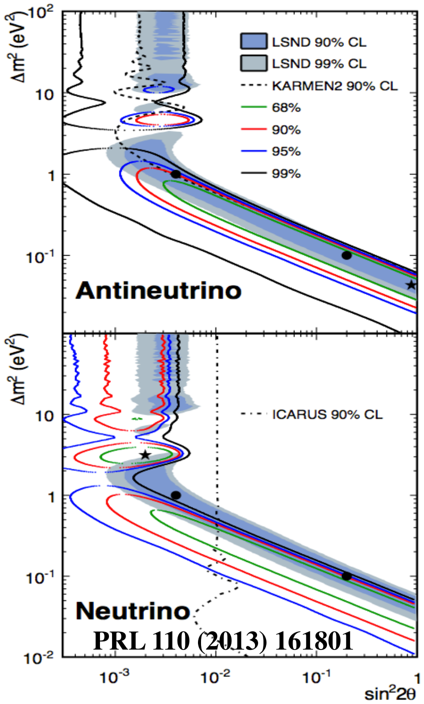
- Leptonic mixing matrix

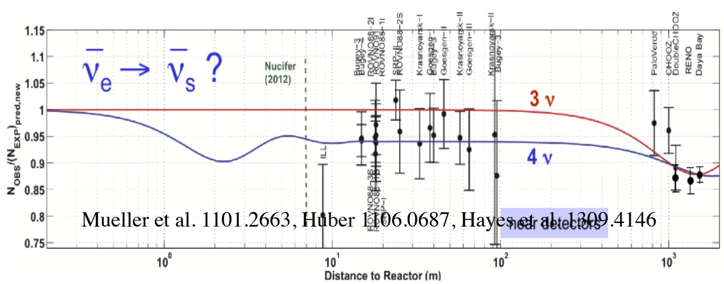
NuFIT 2.0 (2014)

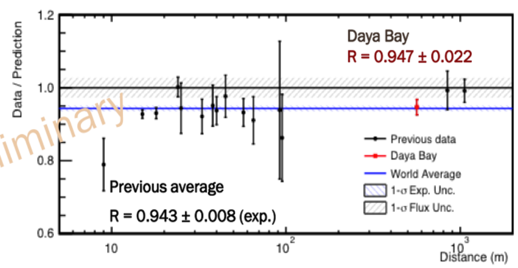
$$|U|_{3\sigma} = \begin{pmatrix} 0.801 \to 0.845 & 0.514 \to 0.580 & 0.137 \to 0.158 \\ 0.225 \to 0.517 & 0.441 \to 0.699 & 0.614 \to 0.793 \\ 0.246 \to 0.529 & 0.464 \to 0.713 & 0.590 \to 0.776 \end{pmatrix}$$

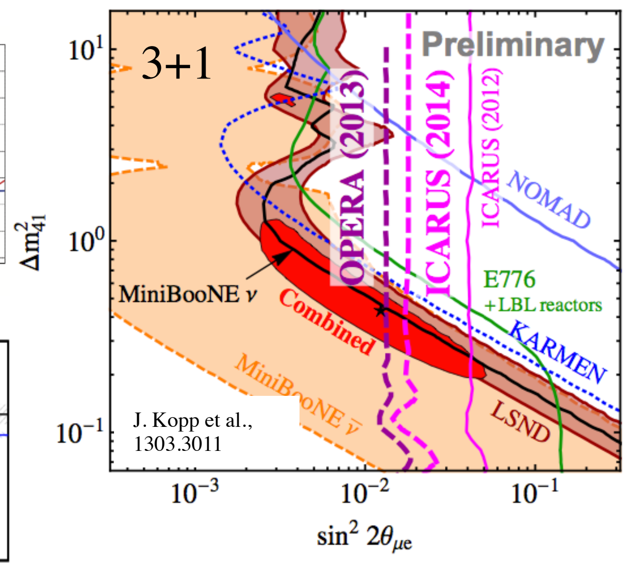
Other Neutrino Results and "Anomalies"

- The field of neutrino physics has also accumulated a collection of measurements that may point to the potential existence of sterile neutrinos with masses around 1 eV beyond the three-flavor paradigm.
- Alternatively, these results may be explained by new physics in neutrino sector, or by a new background component not accounted for (for example in the MiniBooNE analysis).
- These results include:
  - -results of recent short-baseline accelerator (anti)neutrino experiments LSND/MiniBooNE
  - -reactor anomaly
  - -the gallium anomaly
  - -cosmic surveys results

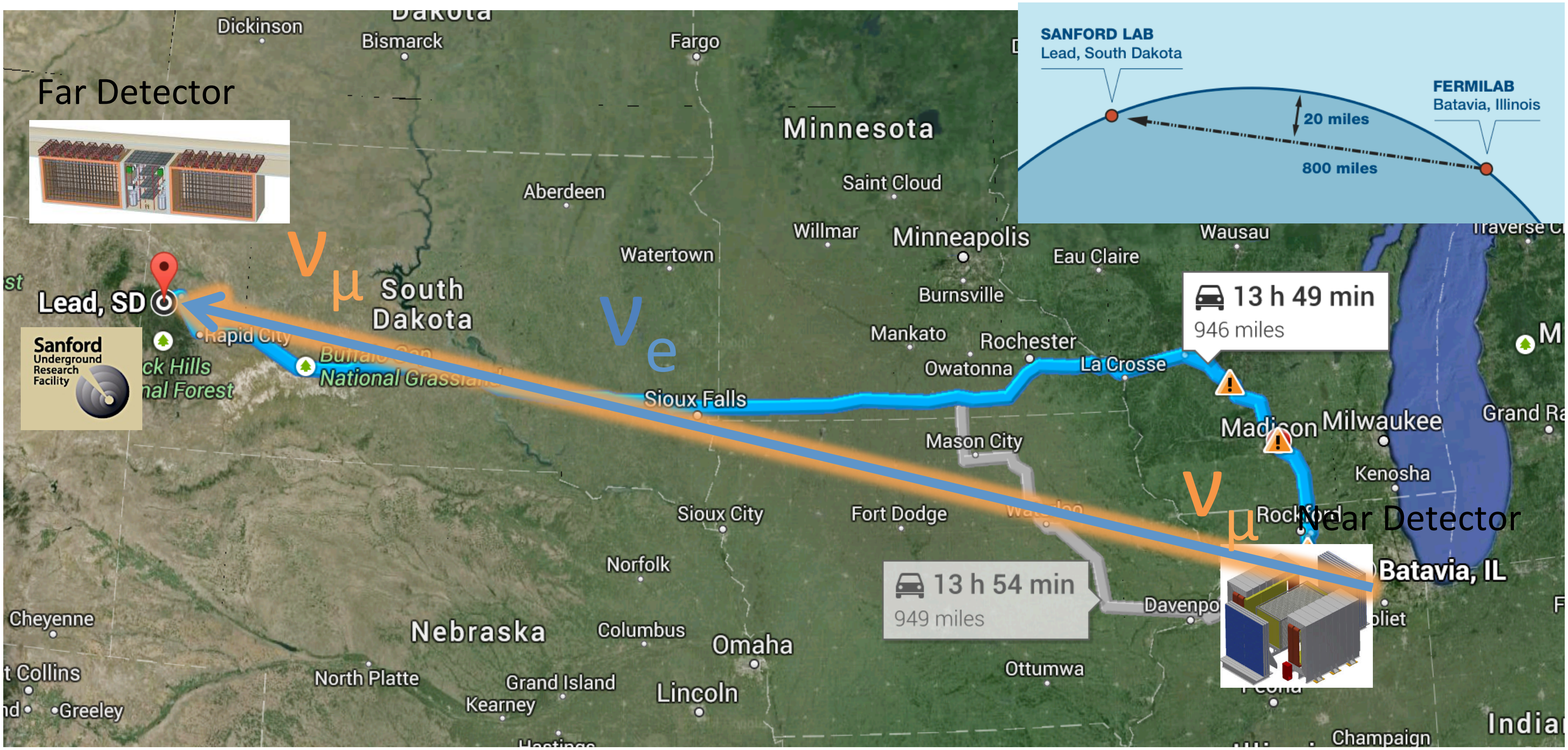








The Long-Baseline Neutrino Experiment (LBNE)



- LBNE is proposed to consists of
  - -an intense neutrino beam originating at Fermilab
  - -near detector systems at Fermilab
  - -at least 34 kt liquid argon time-projection chamber (TPC) at Sanford Laboratory at 4850 foot depth – 1300 km from Fermilab

LBNE Science Goals

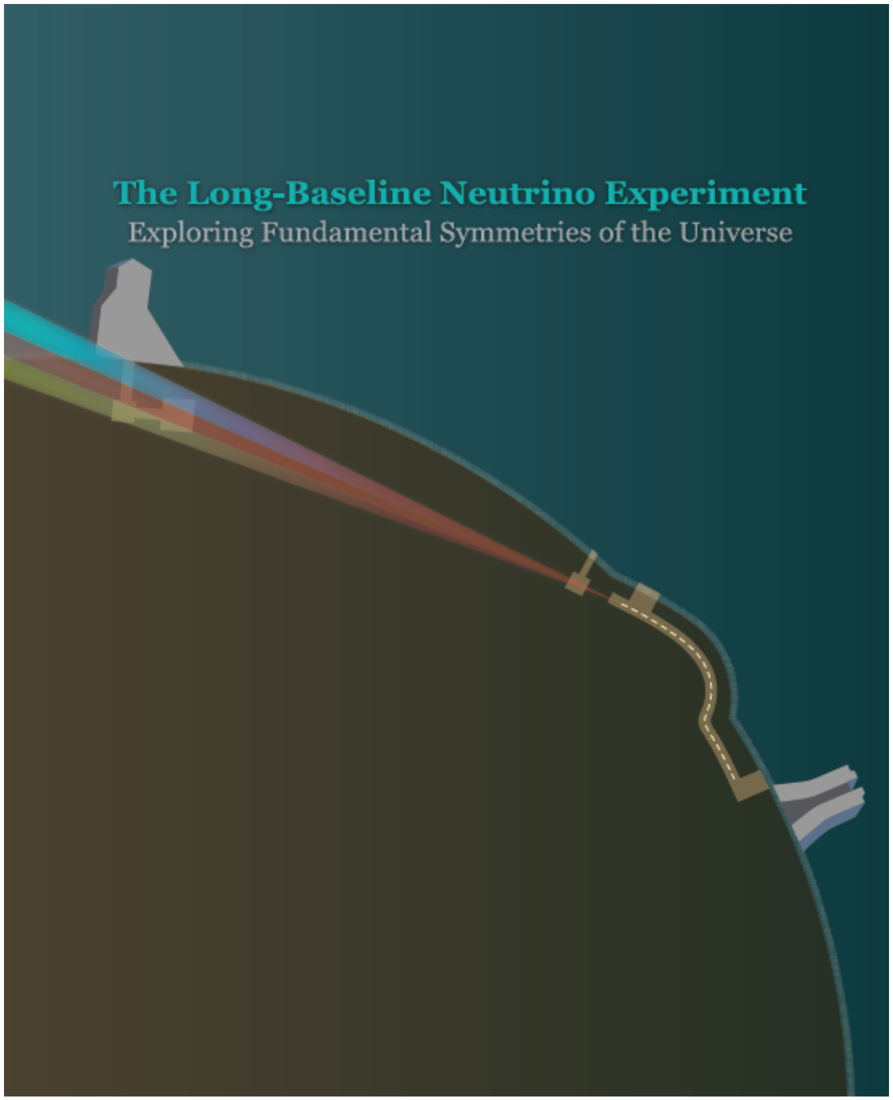
- LBNE is a comprehensive program to measure neutrino oscillation
- LBNE design follows these priorities:
  - -CP violation in neutrino sector
  - -CP phase measurement regardless of its value
  - -Neutrino mass hierarchy determination
  - -Determination of θ_{23} octant and precision parameter measurements
  - -Precision tests of 3-flavor neutrino model.

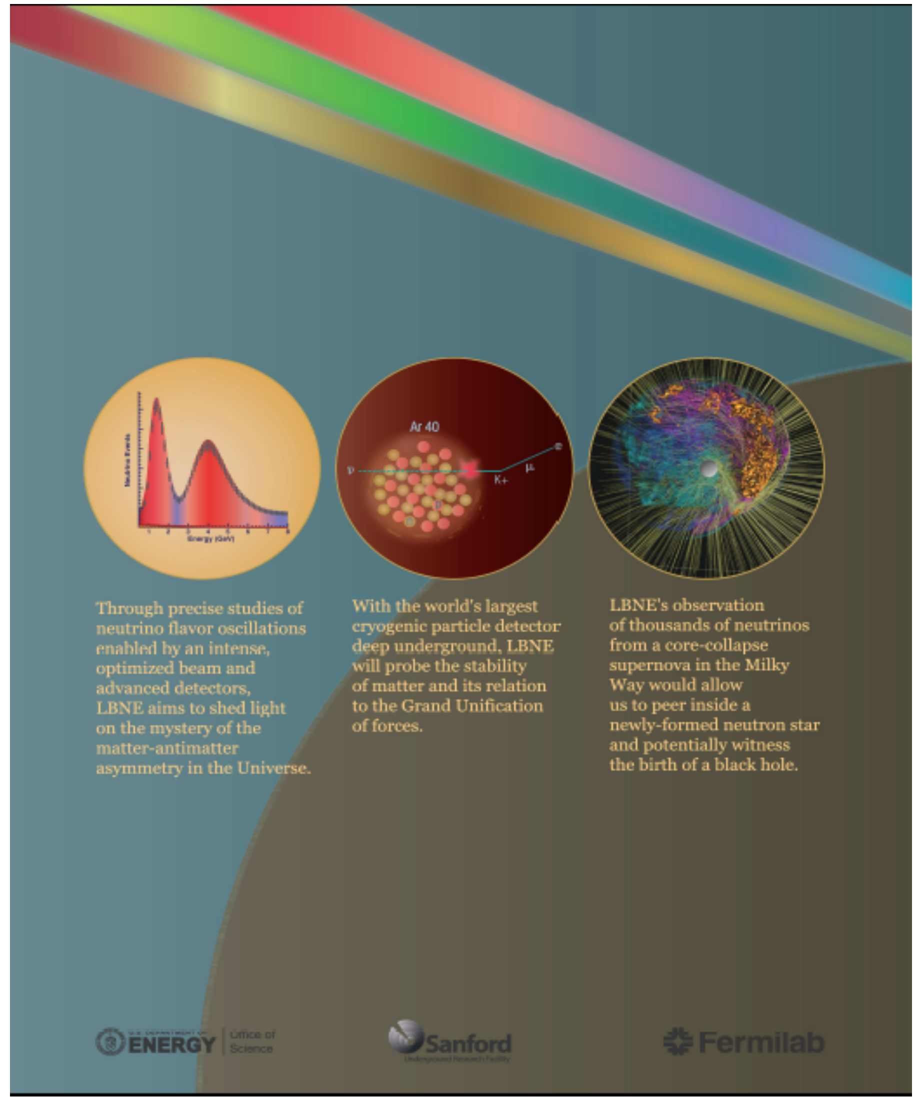
  comprehensive program with beam neutrinos

  - -Atmospheric neutrino measurements (confirmation of mass ordering with independent data)
  - -Nucleon decay
  - -Supernova burst neutrinos
  - -A very capable near detector will have a synergistic scientific program of precision neutrino and weak interaction physics.

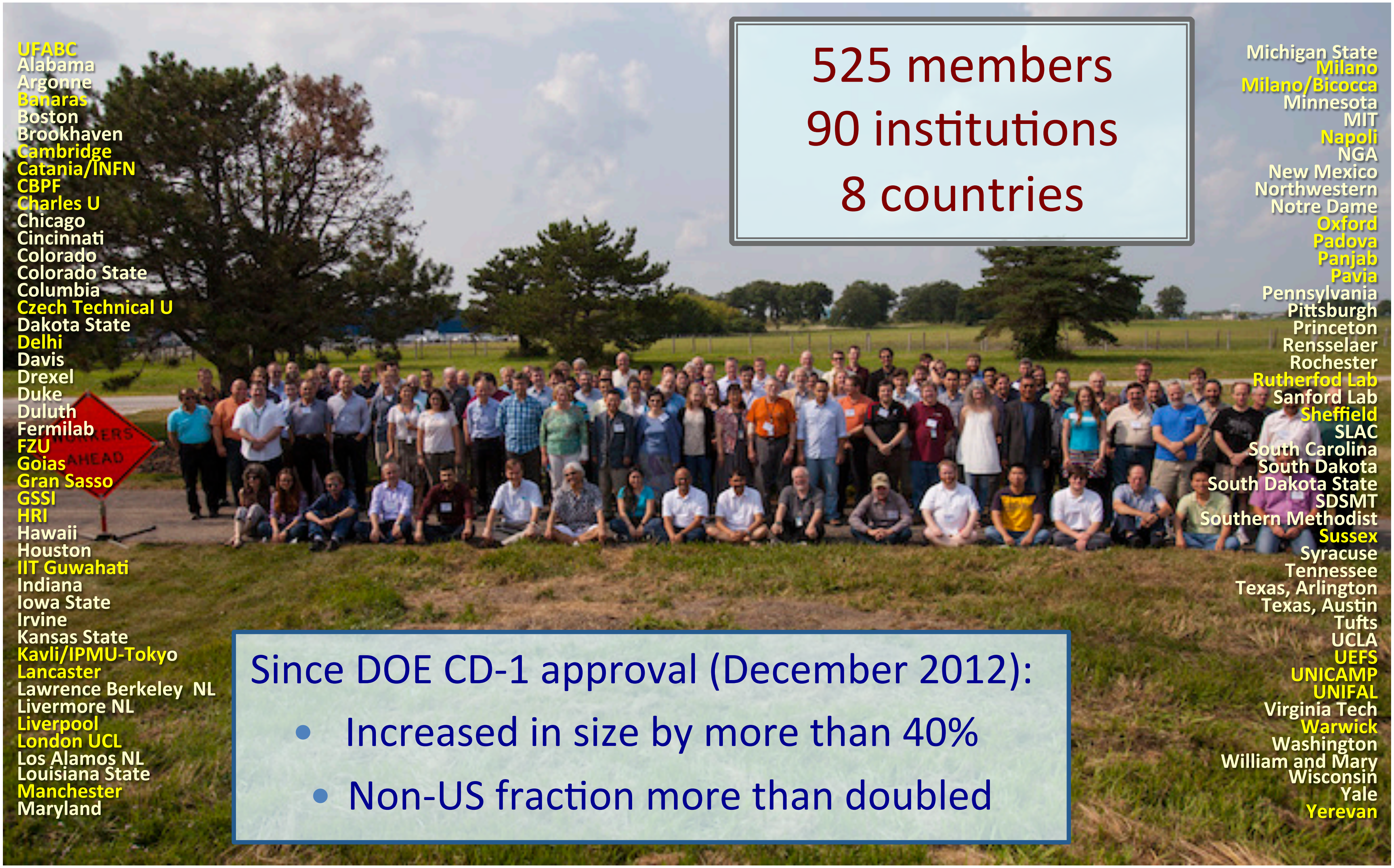
LBNE Science Book

- Comprehensive description of the LBNE Science Program
- The Long-Baseline Neutrino Experiment: Exploring Fundamental Symmetries of the Universe, arXiv:1307.7335





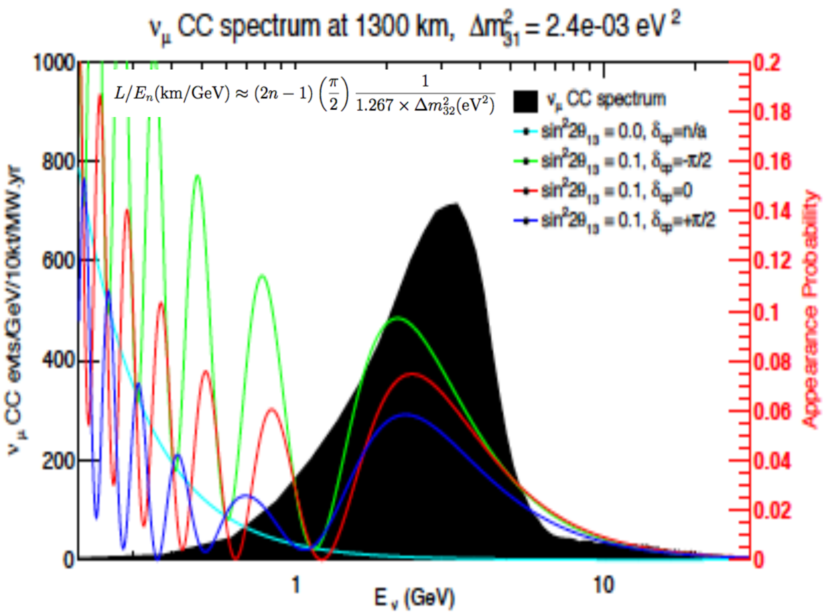
LBNE Science Collaboration



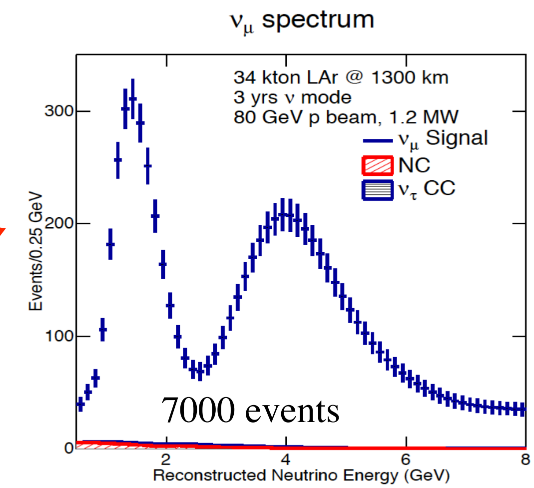
http://lbne.fnal.gov/collaboration/collab_main.shtml

Experimental Technique

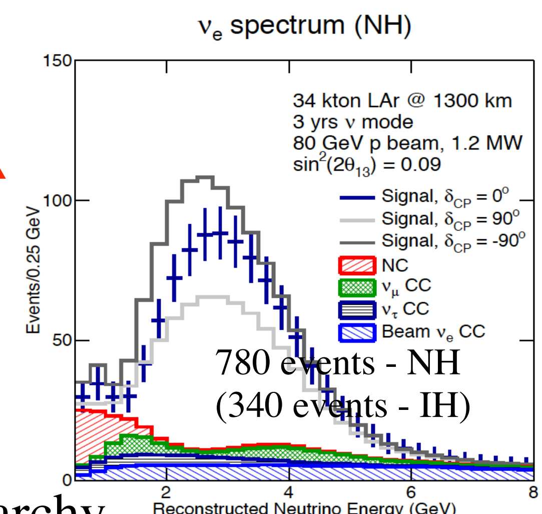
- Produce a pure muon-neutrino beam with energy spectrum matched to oscillation pattern at selected distance.
- Measure spectrum of ν_μ and ν_e at a distant detector.



ν_μ disappearance



ν_e appearance



$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 + \alpha \sin 2\theta_{13} \cos\delta \frac{\sin(aL)}{(aL)} \frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)} \cos\Delta_{32} - \alpha \sin 2\theta_{13} \sin\delta \frac{\sin(aL)}{(aL)} \frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)} \sin\Delta_{32}$$

$$a = G_F N_e \sqrt{2}$$

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E}$$

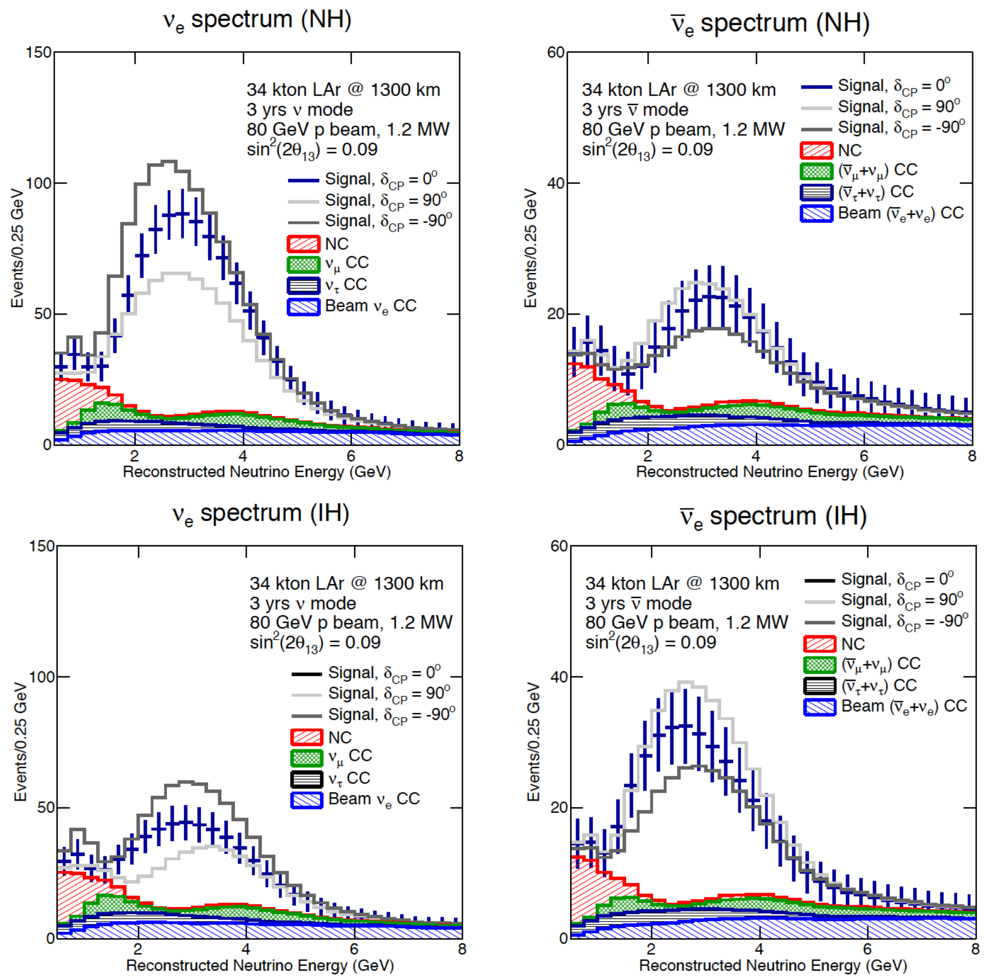
- LBNE is a good choice of beam and distance for sensitivity to CP-violation, CP-phase, neutrino mass hierarchy, and other oscillation parameters within the same experiment.

Event Rates at the Far Detector

GLoBES simulation with global smearing and efficiencies based on ICARUS.

Three years of running each for neutrinos and anti-neutrinos

neutrino running | anti-neutrino running



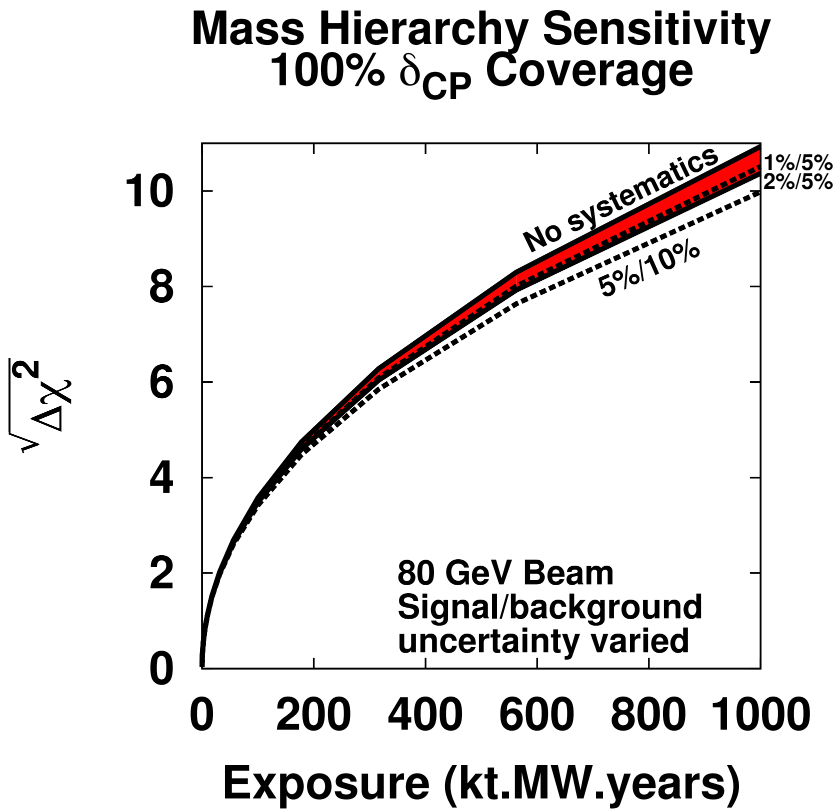
Normal Hierarchy

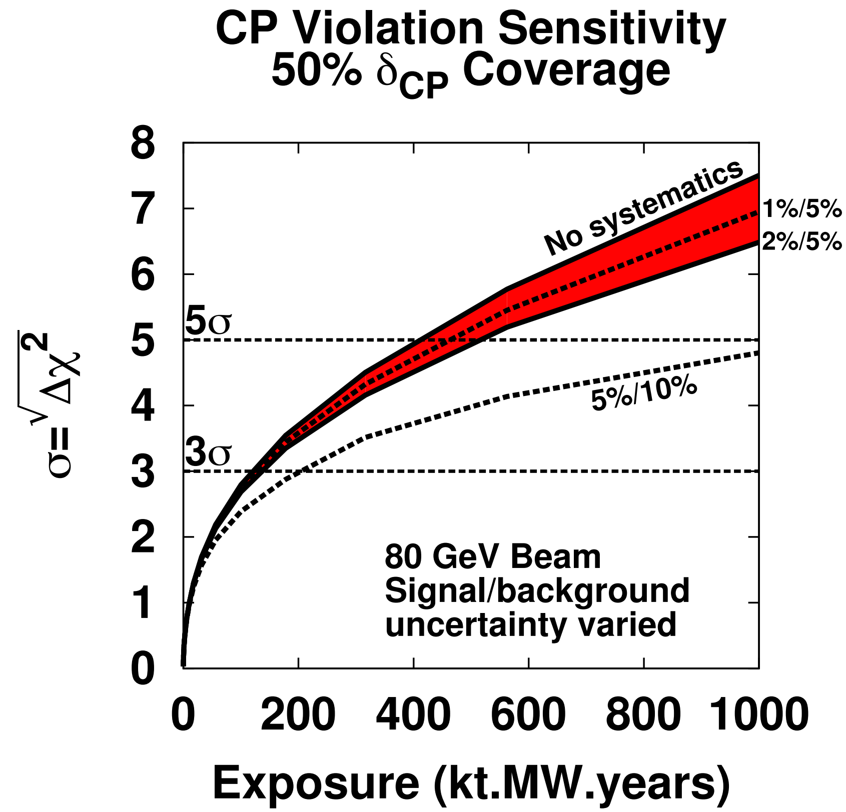
Inverted Hierarchy

Aiming for ~1000 events in neutrinos and ~300 in anti-neutrinos

- In ν_e appearance search aiming at ~1000 events in neutrino run and ~300 events in anti-neutrino run.

Mass Hierarchy and CP Sensitivities

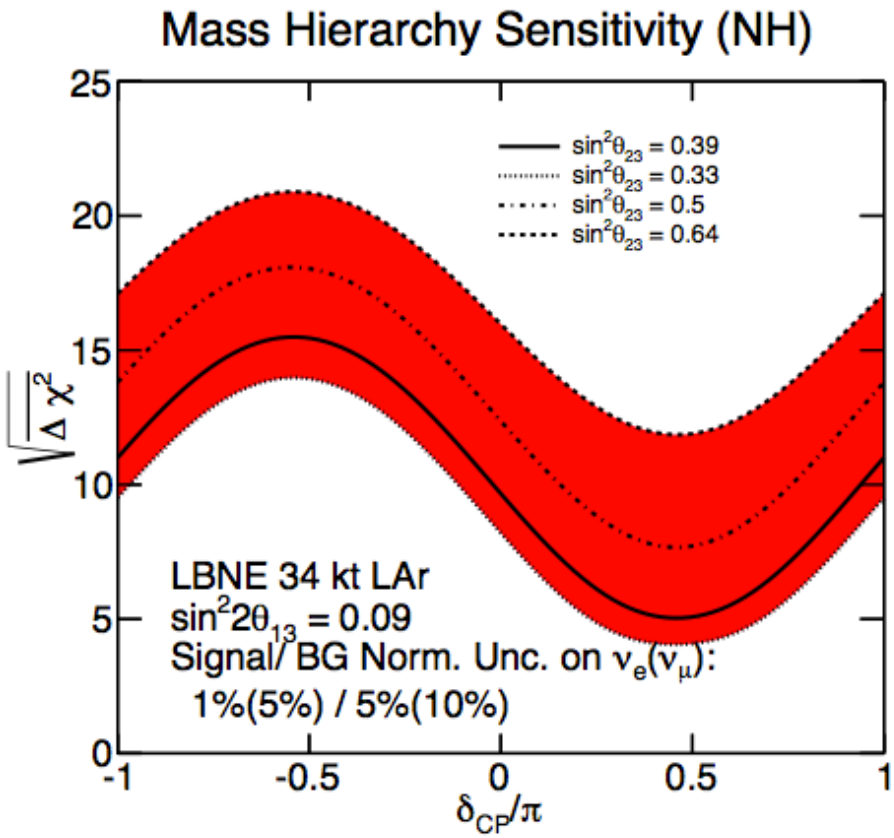


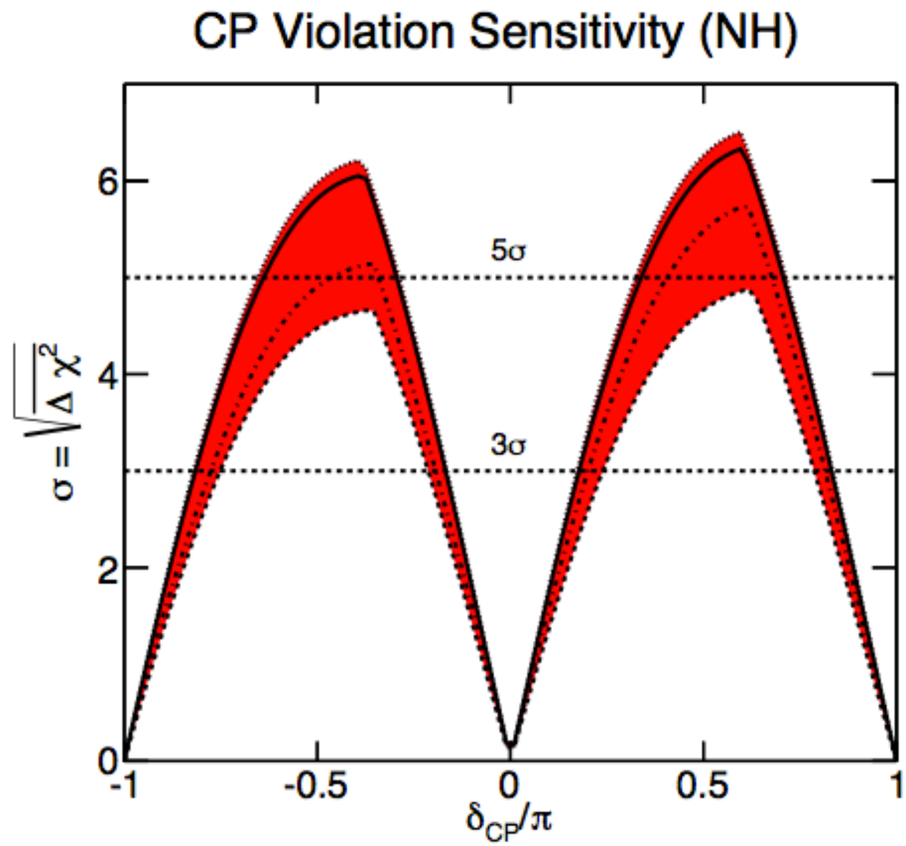


-To get a sense of an expected exposure: for 40 kt FD and 1.2 MW beam it amounts to ~40-50 kt*MW per year.

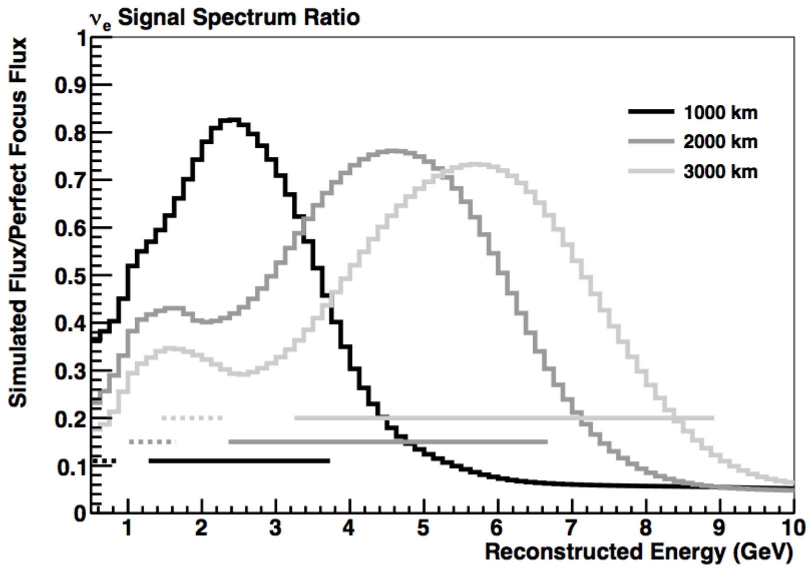
Mass Hierarchy and CP Sensitivities

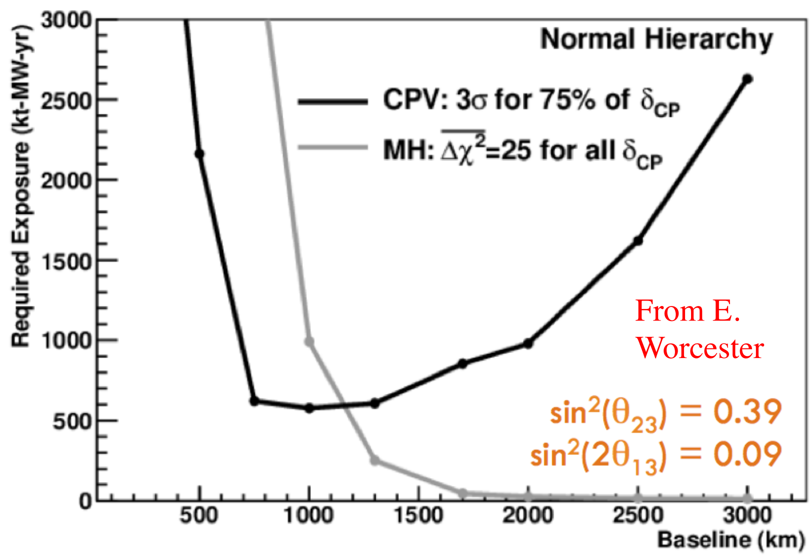
- Exposure: 245 kt.MW.yr = 34 kt x 1.2 MW x (3ν+3ν) years





Is the experimental baseline optimal?

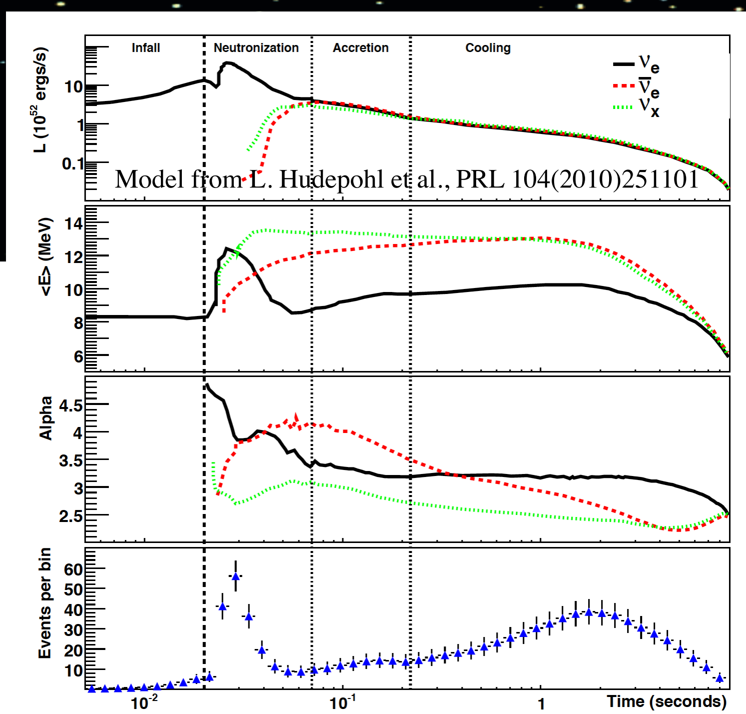




- Based on simulations for Fermilab NuMI proton beam (120-GeV, 1.2 MW).
  -Beam parameters (horn distance, decay pipe length, off-axis beam) optimized depending on distance.
- Baselines 1000-1500 km appear near optimum using Fermilab accelerator beam.
- Studies described in arXiv:1311.0212 (to be updated soon).

Neutrinos from Supernovae

- About 99% of the gravitational binding energy of the proto-neutron star goes into neutrinos.
- Expect 2-3 core-collapse supernovae in the Milky Way per century ≈ 3000 neutrinos in 34kt LBNE for SN@10 kpc
- Unique sensitivity through $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$

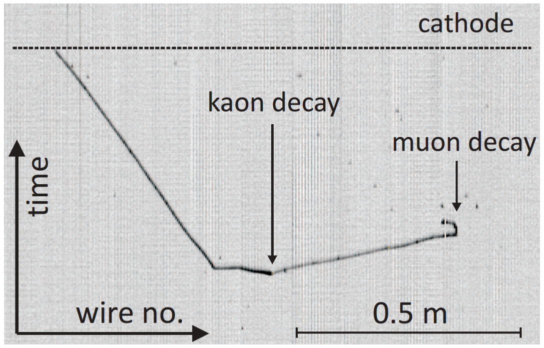


-A large theory effort is underway to understand neutrino related dynamics of the supernova. Both oscillations, mass, and self-interactions have large effects on observables.

e.g. mass hierarchy could have very distinct effects on the spectrum.

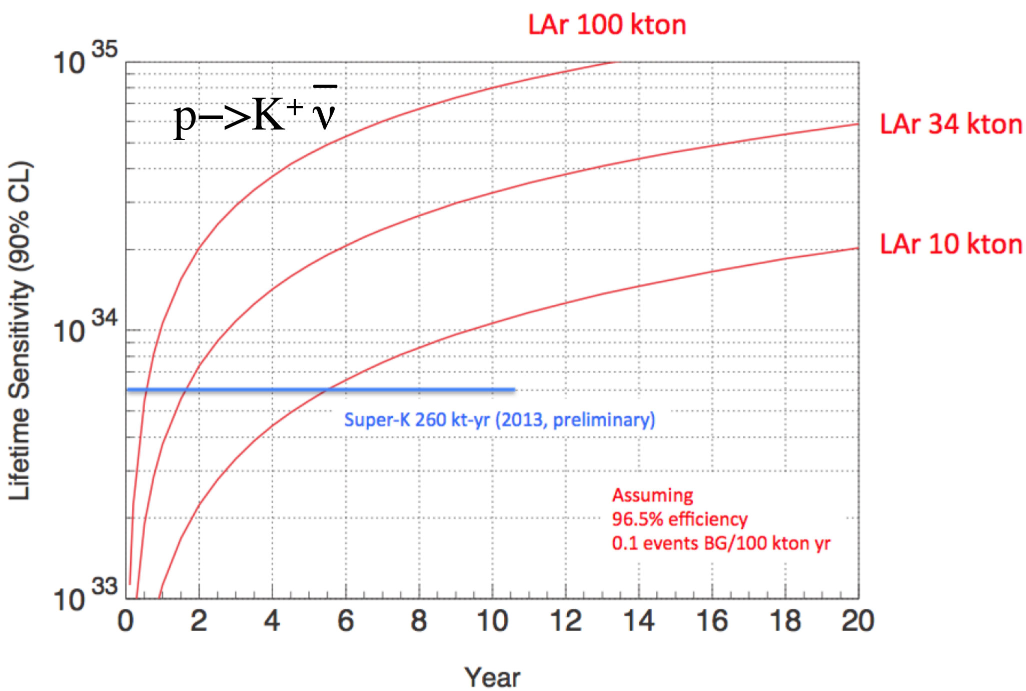
Nucleon Decay

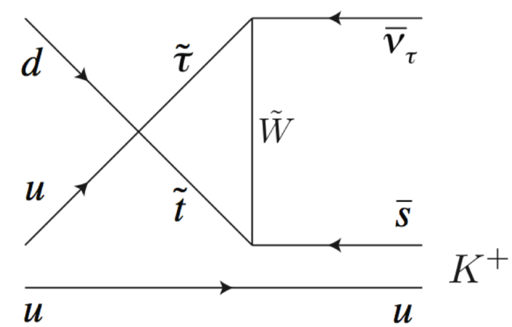
ICARUS



Nucleon decays

Decay Mode	Water Cherenkov Efficiency	Water Cherenkov Background	Liquid Argon TPC Efficiency	Liquid Argon TPC Background
$p \to K^+\overline{\nu}$	19%	4	97%	1
$p \to K^0\mu^+$	10%	8	47%	< 2
$p \to K^+\mu^-\pi^+$			97%	1
$n \to K^+e^-$	10%	3	96%	< 2
$n \to e^+\pi^-$	19%	2	44%	0.8





Kaon modes in LAr with high efficiency and low background, leading to high S/B.

Example: SUSY models

LBNE Experimental Parameters

Wide band neutrino beam from FNAL

- protons: 60-120 GeV, 1.2 MW; upgradable to 2.3 MW
- 10 μs pulses every 1.0 to 1.33 sec depending on proton energy&power.
- Neutrinos: sign selected, horn focused, 0.5 - 5 GeV
- 1300 km through the Earth to Sanford Underground Research Facility.

Liquid argon TPC parameters

- 34 kt fiducial at 4850 ft level. cosmics ~0.1Hz, beam ~ 9k CC/yr
- drift ~3.5 m, field: 500 V/cm, 2 moduls = (14m(H)X 22m(W)X45m(L))
- readout: x,u,v, pitch: 5 mm, wrapped wires
- Max Yield: ~9000 e/mm/MIP, 10000 ph/mm/MIP

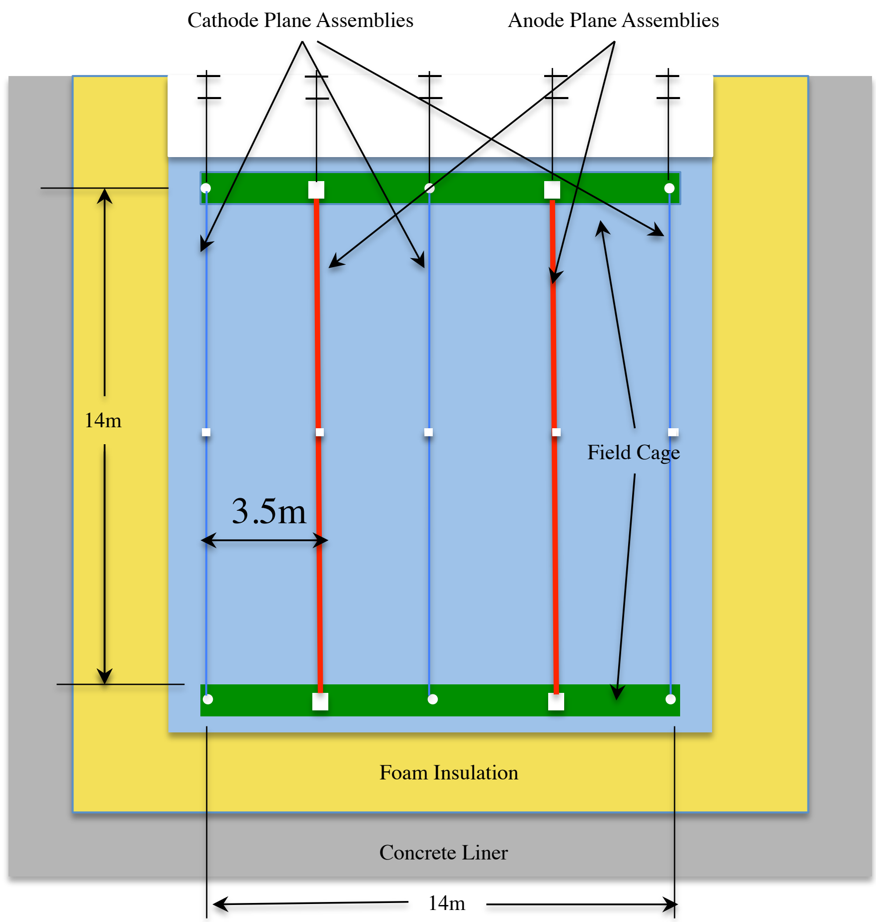
Near detector parameters

- distance ~450 m, ~3M events/ton/MW/yr
- Magnetized Fine Grained Tracker (8 ton) with ECAL, and muon id
- May be supplemented by a small LArTPC (few tons)

-Scale of project is dictated by physics. Beam and ND and FD detectors require high technology. Project can be done in phases with international partners.

2*5kt Detector Design: *Beam's Eye View*

- 2 rows of anode plane assemblies (APA)
- 2 APA assemblies high
- Each module has 4 drift volumes 25m long

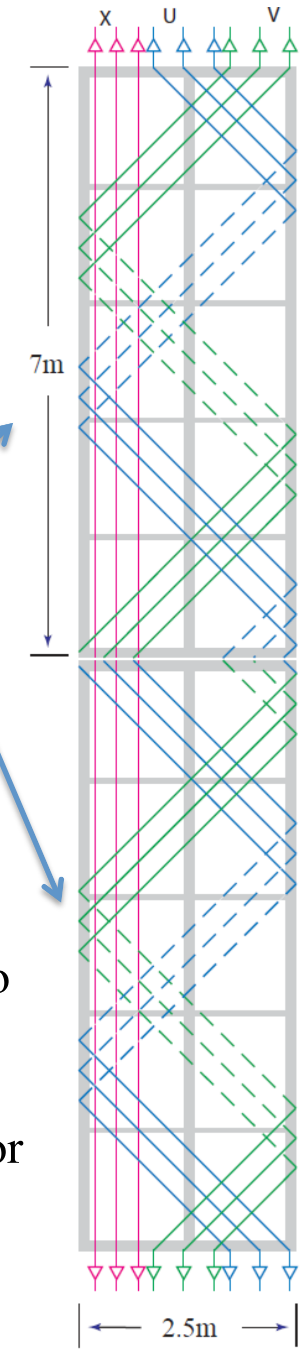


2 modules x 2 wide x 2 high x 10 long = 80 APA planes

Anode Plane Assembly (APA)
- Standard wire chamber construction

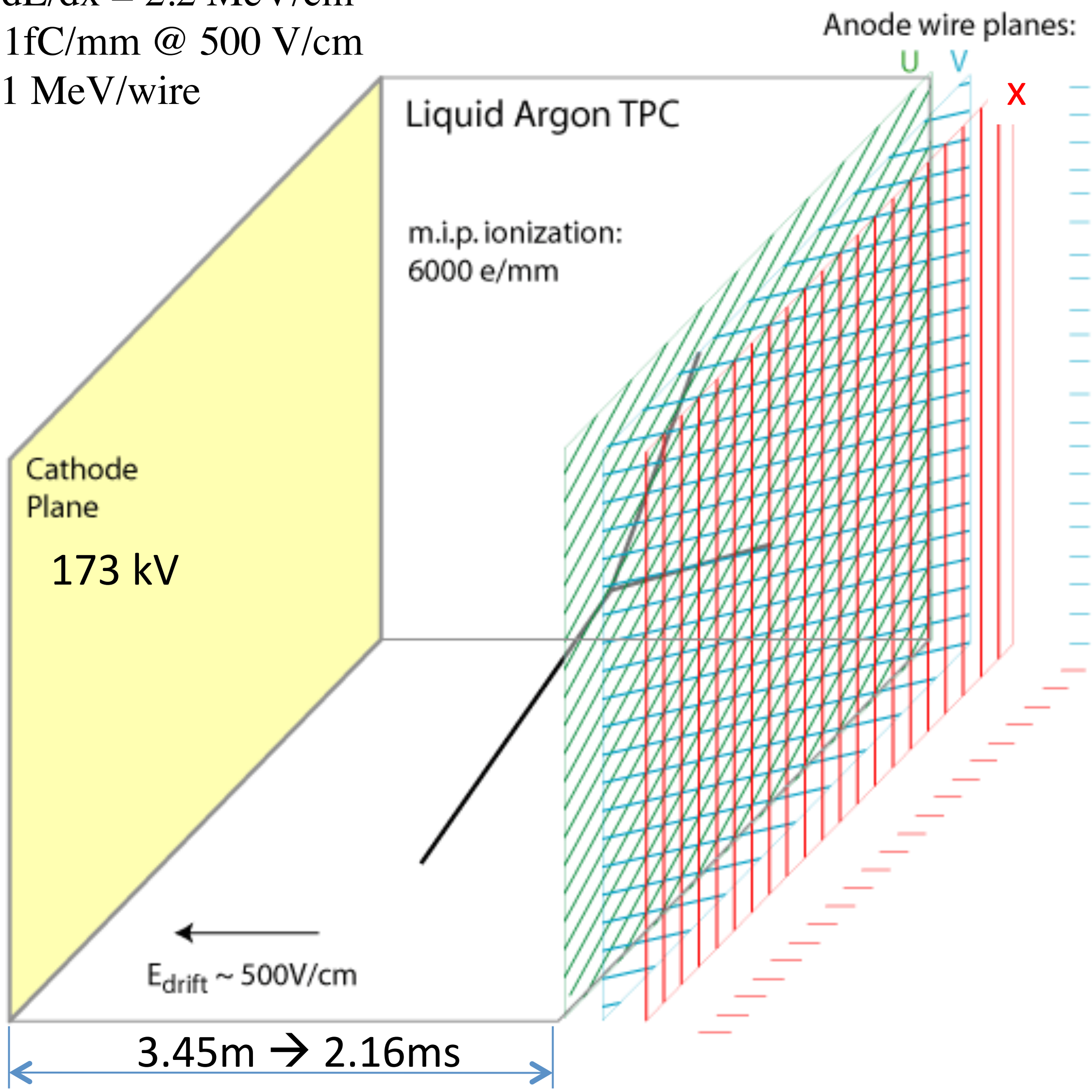
Detector Concept is modular:
2.5m wide 7m long anode plane assemblies.

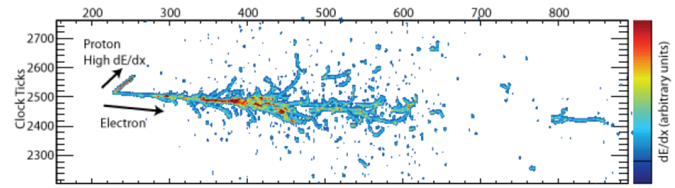
CD-1 design calls for 45° stereo
Investigating changing to 36°
Will reduce ambiguities
→ Simulation critical to detector design!

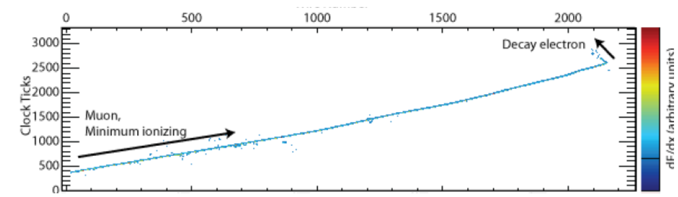


Liquid Argon Time Projection Chamber (TPC) Operation

MIP dE/dx = 2.2 MeV/cm
→ ~ 1fC/mm @ 500 V/cm
→ ~1 MeV/wire

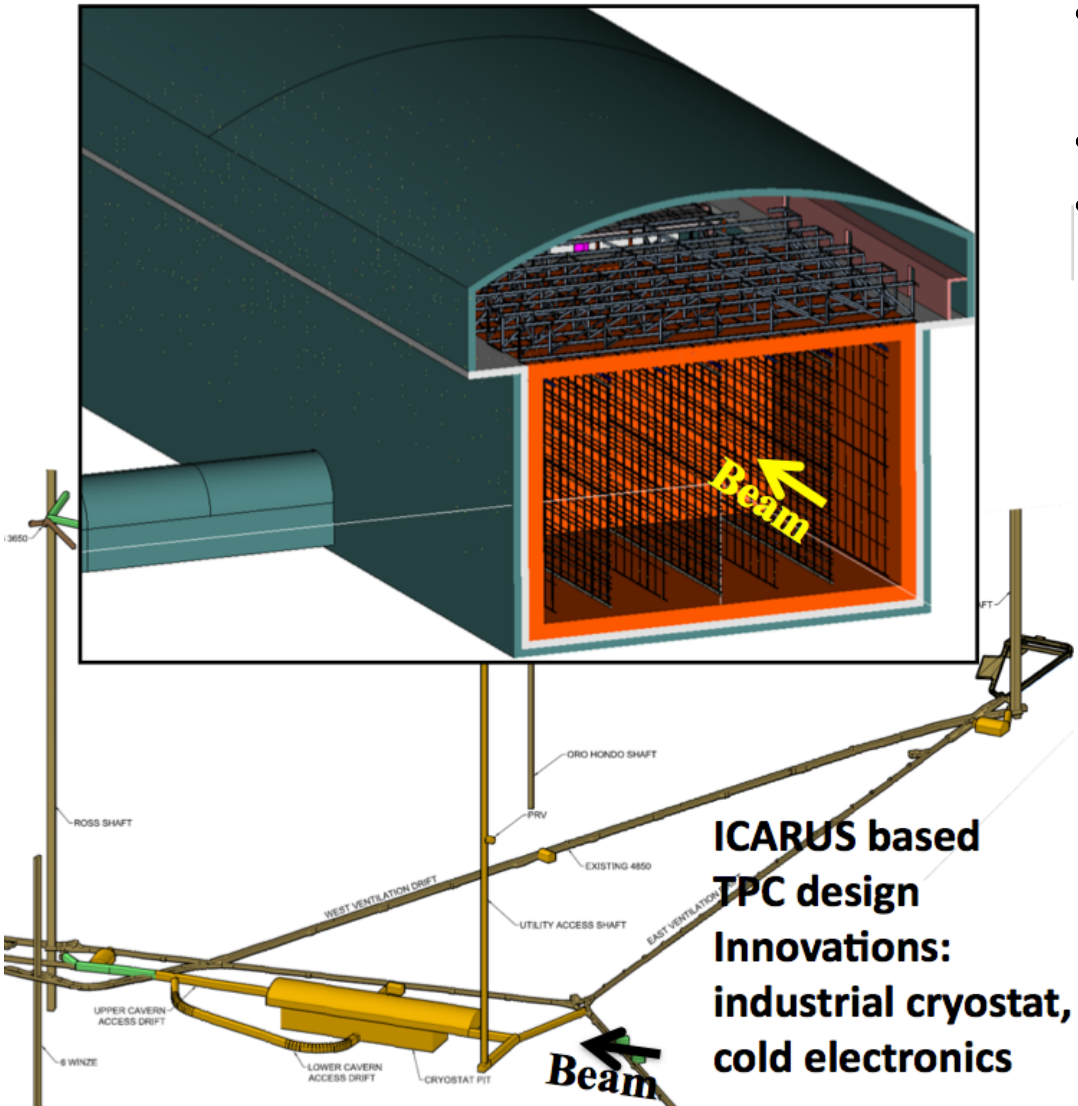






time →

The LBNE Far Detector



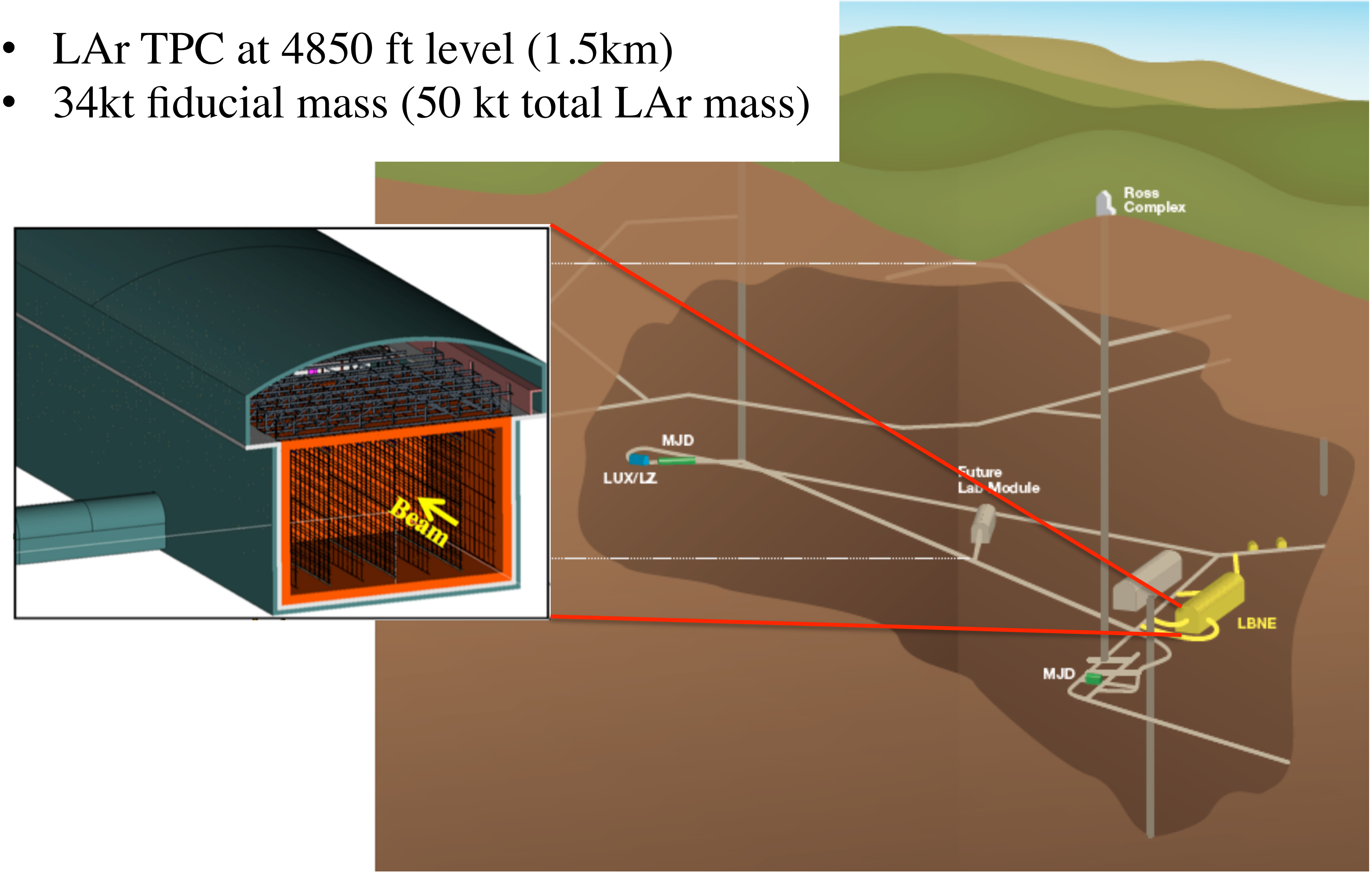
- Two LAr detectors in a common cavern at 4850 ft. depth
- 34 kt fiducial mass
- TPC design:
  - -3.5 m drift length with 500 V/cm
  - -5 mm wire spacing
  - -three stereo views
  - -2 x 108 anode chambers
  - -2 x 275k channels
  - -S/N ~ 10

-Conceptual design allows progress on civil construction, but not fixed.

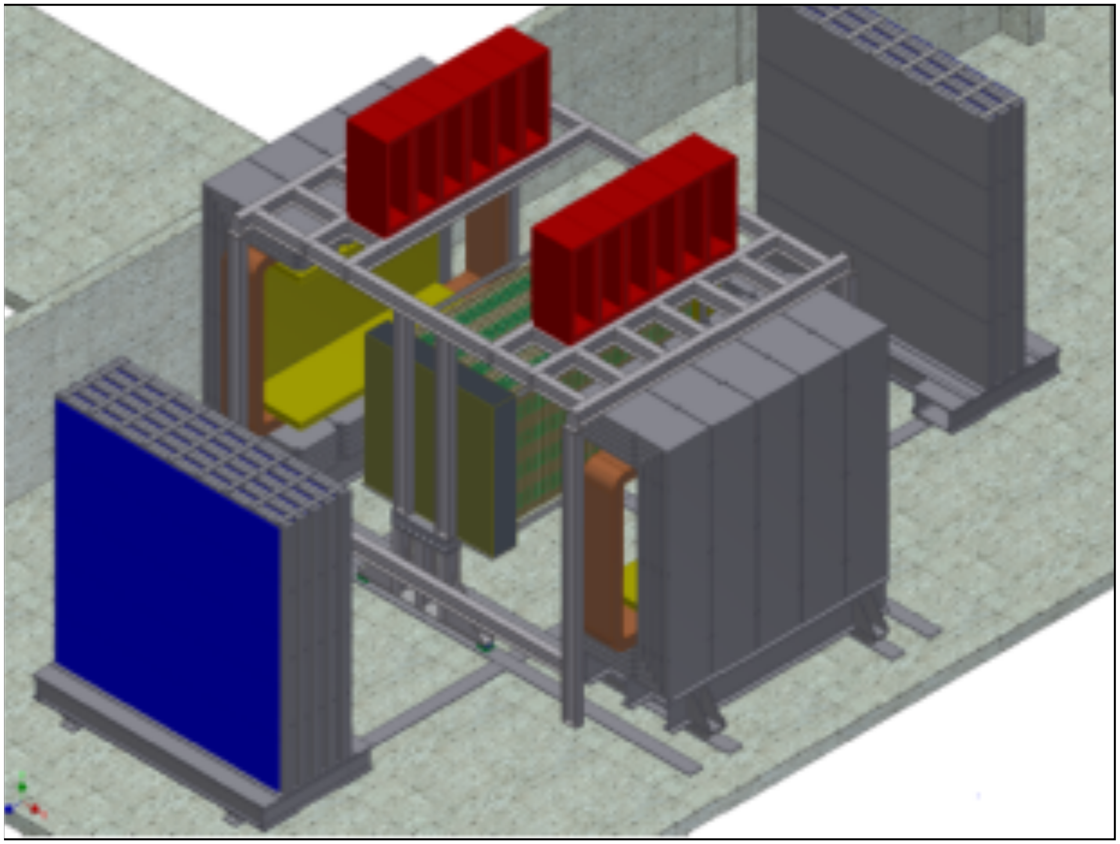
-Design will evolve as the international partnership grows, and may involve multiple modules of different designs.

Far Detector Layout

- LAr TPC at 4850 ft level (1.5km)
- 34kt fiducial mass (50 kt total LAr mass)



Near Neutrino Detector



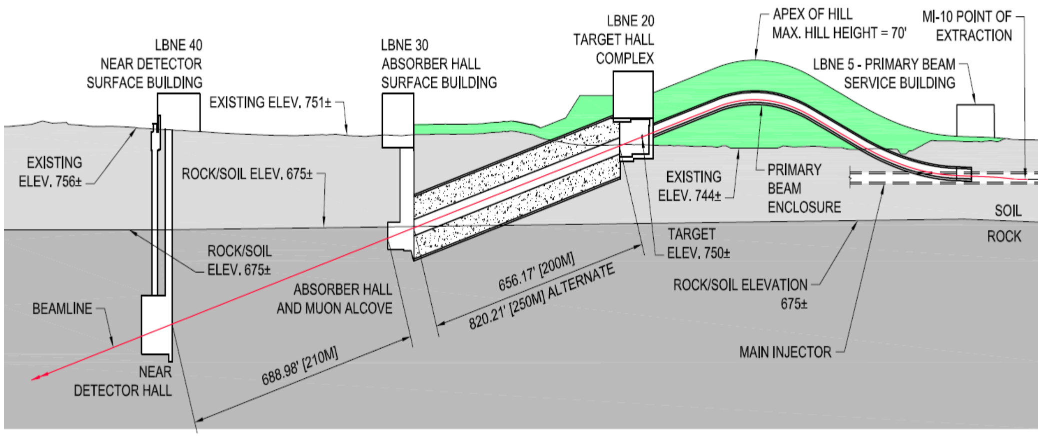
- Fine-Grained Tracker - 460 m from target
  - -Low-mass straw-tube tracker with pressurized gaseous argon target
  - -Relative/absolute flux measurements
  - -High precision neutrino interaction studies $\approx 10^7$ interactions/year
  - -Additional target materials possible
  - -May be supplemented by a small LArTPC (few tons)

-The physics strategy and design of the ND is critical for LBNE.

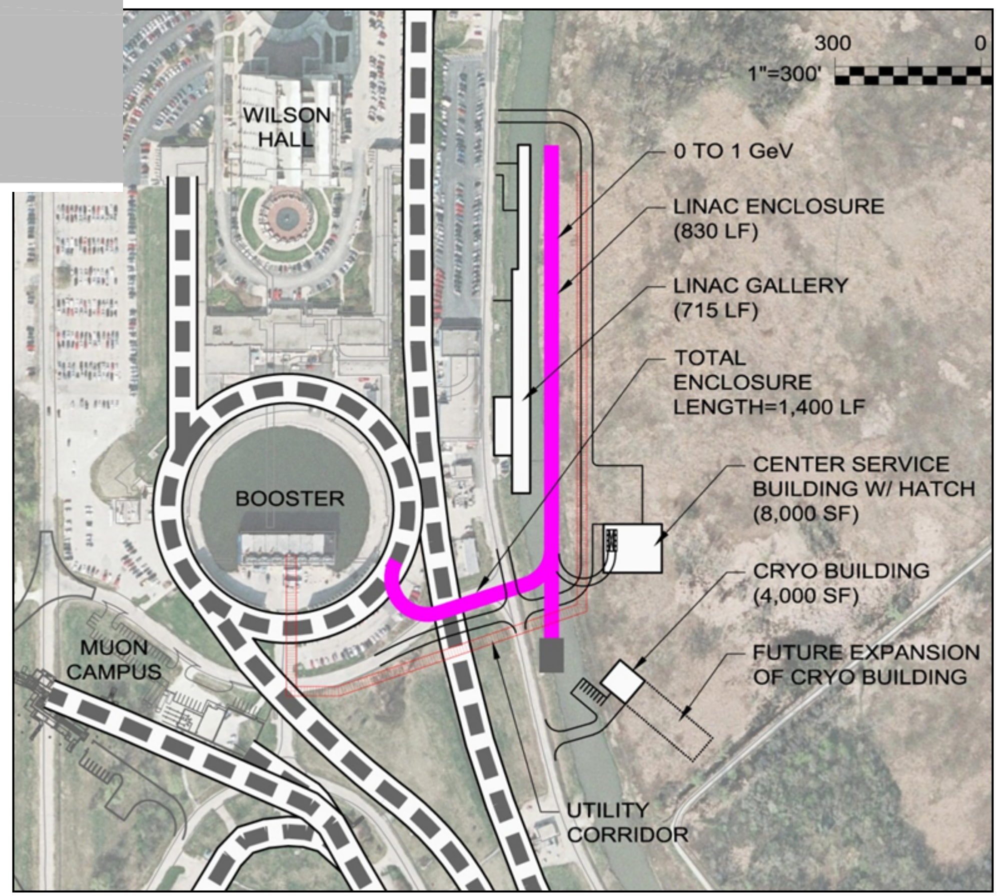
-Simulations, reconstruction and R&D work is in initial phase with input from Indian colleagues.

-Open working meeting at FNAL on July 28-29.

Beam Design and Proton-Improvement-Plan Phase II (PIP-II)



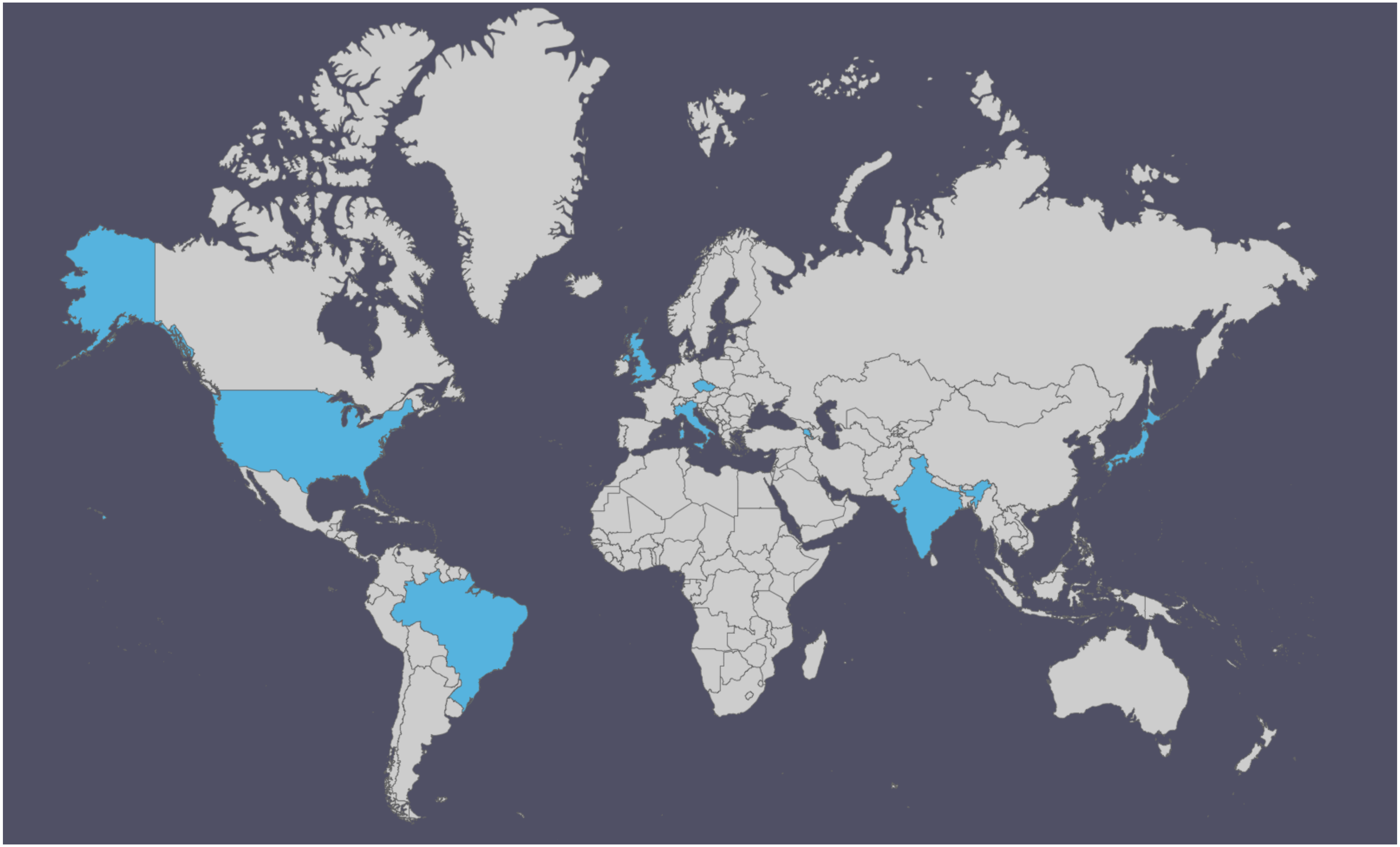
- Innovative design for safety and upgradeability.
- The geotechnical work has started and hill could be ready to be built in 2016.



- For PIP-II replace existing 400 MeV linac with a new 800 MeV superconducting Linac.
- 1.2 MW beam power to LBNE at start-up of experiment.
- Plan is based on well-developed superconducting RF technology.
- Strong support from DOE and in the recent Prioritization Panel report.
- Flexible design - future upgrades could provide > 2MW to LBNE.

International LBNE Collaboration

-Current LBNE Collaboration



International LBNE Collaboration

Brazil (6 Institutions)

- Proposal to funding agencies (FAPESP and CNPq) to be submitted this year.

India (5 institutions)

- Indian Near Detector proposal under review
- Work is proceeding to update the scientific requirements on the Near Detector with Indian scientific participation.
- Collaboration workshop organized in July to evaluate the Near Detector design and potential improvement.

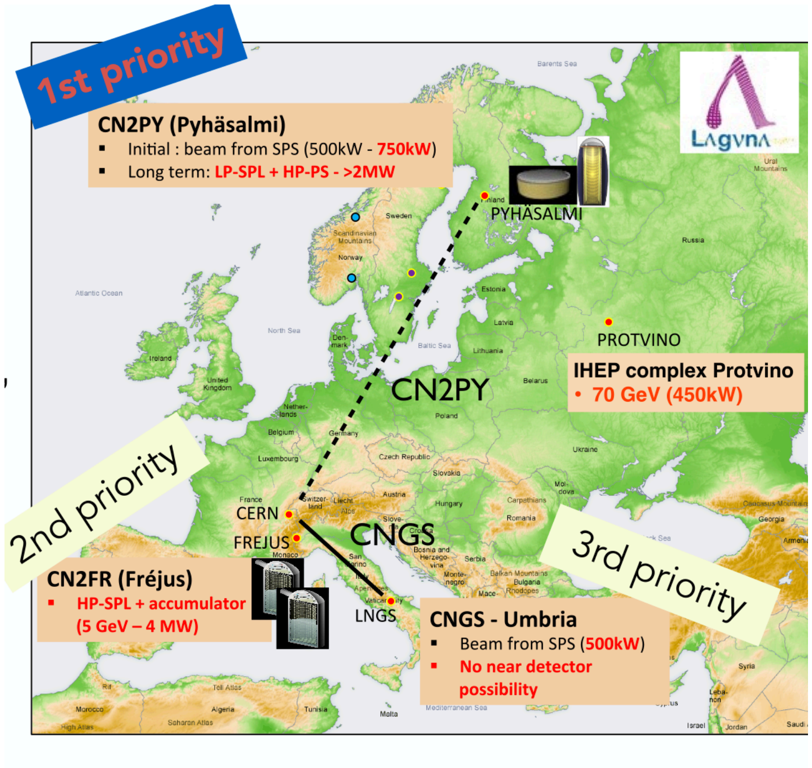
Italy (8 Institutions)

- ICARUS proposal to bring detector to Fermilab
- More groups have shown interest to join.

United Kingdom (10 Institutions)

- SoI accepted by funding agency (STFC), proposal now under review.
- Proposal to build part of LArTPC for LAr1-ND.

International LBNE Collaboration



- Potential International Partners

Laguna/LBNO
-European project for LBL LAr experiment from CERN to Pyhäsalmi in Finland.
-Common LBNE-LBNO integration task force formed.

CERN
-Collaboration on several projects (WA104,WA105, beam) under discussion.
-CERN neutrino platform: R&D activities towards a long-baseline neutrino experiment.

- LBNE will continue to attract further international participation, based on:
  -An exciting world-leading physics program with a detector concept that can achieve the physics goals (underground, >35kt).
  -A well-defined and reliable timeline with first physics starting within a decade.
  -An internationally organized Long-Baseline Experiment and Facility.

P5 Recommendations

- The Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), has now completed its Report, a ten-year strategic plan for high energy physics in the U.S.
- P5 recommendations on neutrino program are all LBNE(F) related:

Recommendation 12: In collaboration with international partners, develop a coherent short- and **long-baseline neutrino program** hosted at Fermilab.

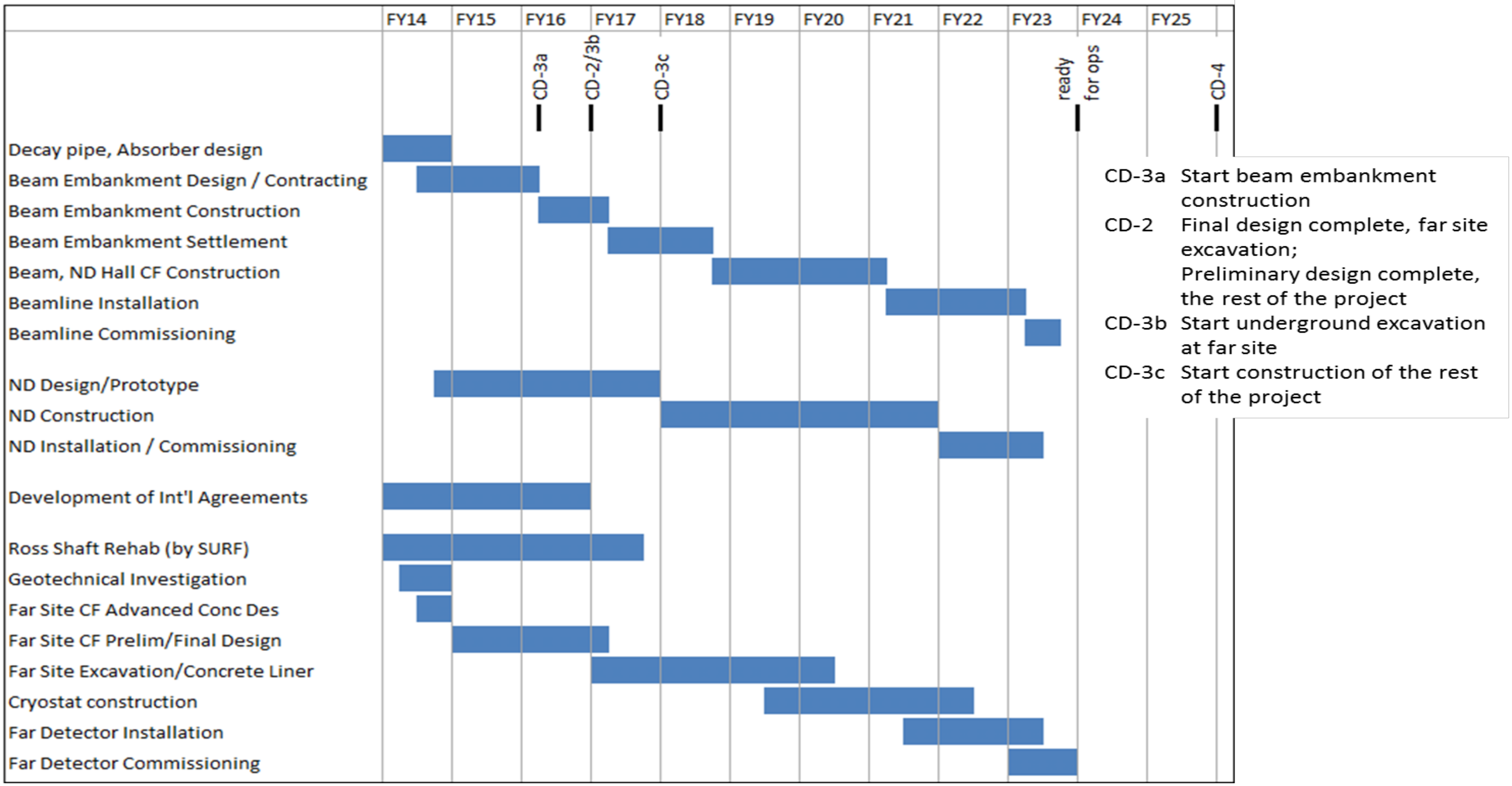
Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to **provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility**.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of **these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab**.

LBNE Schedule

-Plausible Technically Limited Schedule for international LBNF. Depends on resources and international project management.



-Schedule and scope of the experiment will be strongly influenced by new partners.

Recent developments

- Going back to the P5 Recommendation:
  Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

- P5's Minimum Requirements for LBNF:
  -Exposure > 120 kt·MW·yr by 2035 timeframe
  -Far underground detector expandable to 40 kt LAr fiducial volume
  -1.2 MW beam power (upgradable)
  -Detector capable to search for SN bursts, proton decay

- LBNE Statement on P5:

The LBNE collaboration welcomes the recommendations of the recent P5 report and recognizes the need to form a new international collaboration to turn our vision into reality. We are engaging with all interested parties and in particular with the international neutrino physics community through the process initiated by Fermilab and the US DOE. We expect it to culminate in a broader international collaboration.

Internationalization Process

- What is being done?
- Series of meetings to plan the International Long-Baseline Facility
  - International Meeting on Large Neutrino infrastructures, 23-24 June, Paris
  - Follow-up meeting of funding agencies, 14 July, Fermilab
  - Neutrino Summit meeting of neutrino scientific leaders, 21-22 July, Fermilab
    -N. Lockyer established the summit as a means to initiate the process of establishing the necessary international collaboration
    (see the next page).
  - LBNE open workshop on Near Detector Design, 28-29 July, Fermilab
  - LBNE (open) Collaboration meeting, 30 July – 1 August, Fermilab
  - IIEB (Interim International Executive Board) September 23-24, Fermilab
    -Charge of the board is to decide on the new international collaboration for LBNF as specified by P5

Internationalization Process

From Ken Long's July 2014 PAC report

- What came out from the "Neutrino Summit"?
- The community has converged on the development of two concepts:
  - Longer baseline, wide-band approach hosted in the US:
    -Matched to LAr, possibly enhanced through H_2O/H_2O-scint
  - Shorter baseline, narrow-band approach hosted in Japan:
    -Matched to H_2O-Cherenkov
- Community acknowledges:
  - Urgency to establish a coherent and unified path forward or the window of opportunity could close

  and has agreed:
  - A timetable for the preparation of the LOI and the full proposal (CDR)
- It was agreed to establish an
  - *Interim International Executive Board (IIEB)*

  to help form the collaboration and to:
  - Deliver (through the w/gs) the LOI; and to
  - Guide the development of the CDR
- The IIEB will:
  - Report to the emerging collaboration;
  - Be constituted and given its mandate by the ad-hoc funding-agency/lab-director group referred to above;

  and *importantly* will …
  - Be superseded by the collaboration governance as soon as the collab. has been formed;

Interim International Executive Board

- Interim Board Membership

Dario Autiero (IPNL), Edward Blucher (Chicago), Brajesh Choudhary (Delhi), Milind Diwan (BNL), Antonio Ereditato (Bern), Carlos Escobar (UNICAMP), Bonnie Fleming (Yale), Takuya Hasegawa (KEK), Chang Kee Jung (Stony Brook), Ed Kearns (Boston), Yury Kudenko (INR), Thomas Patzak (Université Paris-Diderot), Andre Rubbia (ETH), Carlo Rubbia (GSSI-INFN), Federico Sanchez (Barcelona, IFAE), Kate Scholberg (Duke), Stefan Soldner-Rembold (Manchester), Hiro Tanaka (UBC), Mark Thomson (Cambridge), Bob Wilson (Colorado State), Agnieszka Zalewska(H. Niewodniczański Institute), Marco Zito (Saclay)

Stakeholders: Sergio Bertolucci (CERN), Purniah Boddapati (DAE), Fleming Crim (NSF), Fernando Ferroni (INFN), Jim Siegrist (DOE), John Womersley (STFC)
Ex officio: Ken Long, Joe Lykken, Marzio Nessi, Rob Roser, Jim Strait

Nigel Lockyer (interim Chair)

Stephany Unruh (Board Secretary)

- Board will be additionally aided by the International Governance Stakeholder's Group (chair: Lykken)

Interim International Executive Board

- Aided by International Governance Group

Charge to the Working Group

The working group will produce a draft of an international project governance plan for LBNF. The draft plan will be a short document focusing on:
· Basic governance, accounting, and review structures
· Definition of roles, responsibilities and reporting for the Host Laboratory, external laboratories, the International Collaboration, Central Project Management, and funding agencies

The draft plan, while neither binding nor final, could serve as the basis to begin negotiating bilateral agreements between international stakeholders and the U.S.-Fermilab as host laboratory.

We should deliver an interim report to the iiEB (Interim International Executive Board) at their Fermilab meeting on September 23.

Bosman, Martine
Brito Cruz, Carlos
Cao, Jun
Choudhary, Brajesh
Ereditato, Antonio
Klein, Josh
Lissauer, David
Lykken, Joe
Masiero, Antonio
Medland, Tony
Nessi, Marzio
Purniah
Rubbia, Andre
Salamon, Michael
Strait, Jim
Svoboda, Bob
Zalewska, Agnieszka

Interim International Executive Board

- Interim Board September 23-24 meeting agenda

Day 1 Agenda

8:00 – 8:30	Continental Breakfast (1 East)
8:30 --8:40	Welcome & logistics/process for decision making -- Nigel Lockyer
8:40 – 9:00	Background Context for this meeting -- Ken Long/Rob Roser
9:00 – 9:30	Goals for this meeting and process for moving forward -- Rob Roser/Ken Long
9:30 – 9:45	View from DOE-- Jim Siegrist (5 min + discussion)
9:45 – 10:00	Status from the "international governance" stakeholders committee --Joe Lykken • How does the DOE project system work and how will the host lab (Fermilab) interface with this global project, the international funding agencies and community
10:00 – 10:30	COFFEE BREAK
10:30 – 11:00	What will be the mechanisms by which CERN can help Europe organize and work with the host lab– Sergio Bertolucci
11:00 – 11:15	Timeline for a new site approval? Michael Weis, DOE, Fermi Site Manager (guest)
11:15 - 12:30	Discussion 1a: Scientific strategies, co-existing with HyperK --Joe Lykken/Andre Rubbia
12:30 – 1:30	LUNCH – 2nd Floor Cross Over
1:30 –1:45	Role of SB program in preparation for the LB program— Bonnie Fleming/Carlo Rubbia
1:45 – 3:00	Discussion 1b -- Scientific Strategies –Continue discussion– Andre Rubbia/Joe Lykken
3:00 – 3:30	Coffee Break
3:30 – 3:50	LBNE Project Status-- The budget, what has been spent/accomplished. What do we wish to accomplish in FY15 – Elaine McCluskey (guest)
3:50 – 4:10	LBNO--What has been learned for a Fermilab hosted experiment? – Dario Autiero
4:10 – 4:25	Timeline of Accelerator Complex for Neutrinos – PIP/PIPII -- Paul Derwent (guest)
4:25 – 4:45	Discussion 2-- Optimal Beam Characteristics – Marzio Nessi/Yury Kudenko
4:45 – 5:30	Discussion 3 -- Formation of Working Groups -- Kate Scholberg/Mark Thomson
5:30	Adjourn for the day

Day 2:

8:00 – 8:30	Continental Breakfast (1 East)
8:30 – 9:00	Thoughts/questions/comments from Day 1 – Rob Roser/Ken Long
9:00 –10:00	Discussion 4: Transition plans/new collaboration--Milind Diwan/TBD*
10:00 – 10:30	COFFEE BREAK
10:30 – 11:00	Discussion 5: Selecting (co)-spokespeople -- Chang Kee Jung/ Stefan Soldner-Rembold
11:00 – 12:00	Discussion 6 Drafting Bullets to form the basis for LOI – Ken Long/Rob Roser
12:00-- 12:05	Date of next meeting-- Rob Roser
12:05	Adjourn

- Ideally, the IIEB discussion will be concluded with an LOI.

Interim International Executive Board

- Interim Board September 23-24 meeting agenda

Day 1 Agenda

8:00 – 8:30	Continental Breakfast (1 East)
8:30 --8:40	Welcome & logistics/process for decision making -- Nigel Lockyer
8:40 – 9:00	Background Context for this meeting -- Ken Long/Rob Roser
9:00 – 9:30	Goals … this meeting and process for moving forward -- Rob Roser/Ken Long
9:30 – 9:45	Vie… …iegrist (5 min + discussion)
9:45 – 10:00	S… …nance" stakeholders committee --Joe Lykken • Ho… …how will the host lab (Fermilab) interface w… …nding agencies and community
10:00 – 10:30	COFFEE BREAK
10:30 – 11:00	What will be the mechanisms by which CERN … with the host lab– Sergio Bertolucci
11:00 – 11:15	Timeline for a new site approval? Michael Weis, DOE, Fermi Site M…
11:15 - 12:30	Discussion 1a: Scientific strategies, co-existing with HyperK --Joe Lykken/Andre …
12:30 – 1:30	LUNCH – 2nd Floor Cross Over
1:30 –1:45	Role of SB program in preparation for the LB program— Bonnie Fleming/Carlo Rubbia
1:45 – 3:00	Discussion 1b -- Scientific Strategies –Continue discussion– Andre Rubbia/Joe Lykken
3:00 – 3:30	Coffee Break
3:30 – 3:50	LBNE Project Status-- The budget, what has been spent/accomplished. What do we wish to accomplish in FY15 – Elaine McCluskey (guest)
3:50 – 4:10	LBNO--What has been learned for a Fermilab hosted experiment? – Dario Autiero
4:10 – 4:25	Timeline of Accelerator Complex for Neutrinos – PIP/PIPII -- Paul Derwent (guest)
4:25 – 4:45	Discussion 2-- Optimal Beam Characteristics – Marzio Nessi/Yury Kudenko
4:45 – 5:30	Discussion 3 -- Formation of Working Groups -- Kate Scholberg/Mark Thomson
5:30	Adjourn for the day

Day 2:

8:00 – 8:30	Continental Breakfast (1 East)
8:30 – 9:00	Thoughts/questions/comments from Day 1 – Rob Roser/Ken Long
9:00 –10:00	Discussion 4: Transition plans/new collaboration--Milind Diwan/TBD*
10:00 – 10:30	COFFEE BREAK
10:30 – 11:00	Discussion 5: Selecting (co)-spokespeople -- Chang Kee Jung/ Stefan Soldner-Rembold
11:00 – 12:00	Discussion 6 Drafting Bullets to form the basis for LOI – Ken Long/Rob Roser
12:00-- 12:05	Date of next meeting-- Rob Roser
12:05	Adjourn

Eventually the decisions and action items from the board will be posted here.
https://indico.fnal.gov/conferenceDisplay.py?confId=8937

- Ideally, the IIEB discussion will be concluded with an LOI.

How to get there (to the LBNE)?

- Through the LBNE Project organization
  - -Engineering design
  - -Prototyping
  - -Construction
- The LBNE Project has a well understood and reviewed design sufficient to baseline and construct the project.
- At the same time the LBNE Project is well positioned to take advantage of R&D in the US or internationally that may reduce cost or risks, or improve performance.
  - -Scientific effort required to support the design and prototyping
  - -Includes simulation effort, effort to operate the prototypes and analyze the prototype data.

LBNE R&D Needs

-LBNE has established R&D Coordination Committee that produced a R&D briefing document (available at LBNE FNAL sharepoint page).

-Summary of Current Critical R&D Tasks Chapter

6. Summary of Current Critical R&D Tasks

A list of currently identified critical R&D tasks that could enhance the experiment is included here. This list includes dates by which the results would be needed in order for the Project to capitalize on them (i.e. before construction of the related item).

- Detector design validation studies with 35-ton prototype — 2017
- Demonstration of cold digital electronics — 2017
- Design of the beamline hadron monitor — 2017
- Improved response of target materials to 1.2 MW proton beam — 2017
- Beam muon measurement systems prototyping, simulations — 2017
- Near Detector prototyping, verification of requirements, simulation — 2018
- Investigation of LArTPC integrated with FGT Near Neutrino Detector — 2018

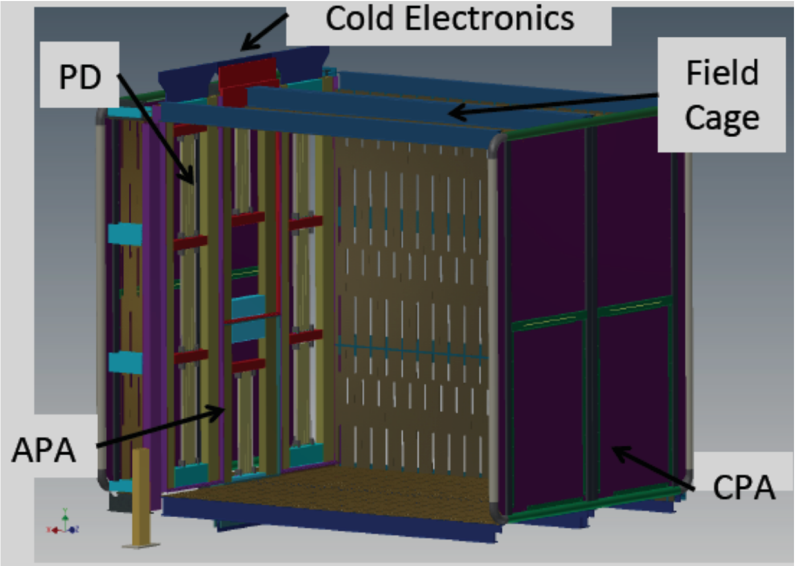
Some R&D items may further improve physics performance and could come later. Conceptual work on these items should be pursued now, since they could significantly affect the integration of the rest of the components in time for the experiment to capitalize. These are listed here:

- More efficient light collection systems — 2018
- Improved argon purification — 2018
- Improved cryogenic liquid processing (microphonics, maintenance) — 2018
- Improved understanding of HV breakdown in LAr — 2018
- Detector calibration test beam measurements — 2021
- Development of target and horns for improved flux spectrum — as soon as available
- Development of target and horns for 2.3 MW — > 2025

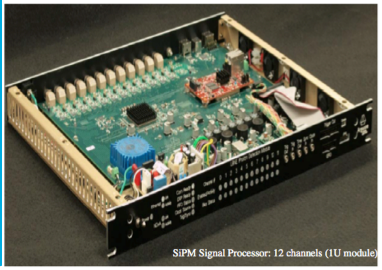
Far Detector Related R&D

- 35 ton detector prototype for the LBNE
  -cryostat performance demonstrated successfully in Phase I (completed)
  - Test membrane technology
  - Cryo-system design

  -Phase II in 2015 will demonstrate the LBNE design
  - Full cold electronics readout chain
  - Integration of TPC and photon detection system
  - APA with wrapped wire planes



TPC Anode Plane



Photon detector R&D

Inside cryostat

-R&D on liquid argon technology essential for designing and building 35 k-ton detector.

External Projects

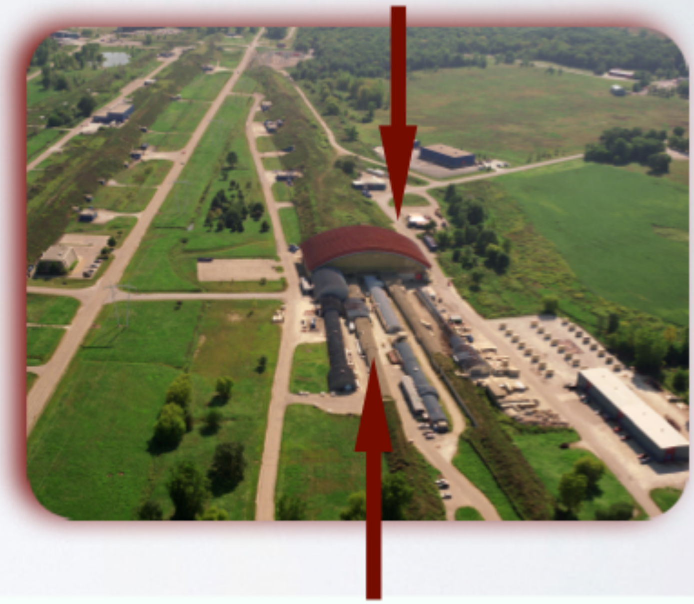
- One of the approached to address R&D needs of LBNE is collaborating with so-called "external projects" that may be relevant to LBNE, to address the LBNE relevant R&D issues.
- These include LAr detectors that are outside of the LBNE project, including CAPTAIN, MicroBooNE, LAr1-ND, ICARUS, LArIAT and WA104 and WA105 at CERN.
- Several of these projects are proposed to be exposed to either charged particle, neutron, or neutrino beams of varying energy.
- These will provide large data sets of neutrino events in LArTPCs that will help develop reconstruction and analysis algorithms and provide detailed cross section measurements that will help LBNE make use of its FD data.
- In particular, LArIAT and WA105 propose to expose LArTPCs to charged particle test beams, providing valuable calibrations to support the analysis of LBNE data.

LArIAT

F. Cavanna, J. Raaf

- LArIAT is a test beam experiment designed to measure details of the detector response to charged particles of known energy and type.
  - LArIAT is the first precision **charged particle** test beam with LAr TPC !

    (Only earlier LAr-TPC test beam was T32 at JPARC with coarser strip, single plane read-out)
- The experiment is being assembled at FNAL Test Beam Facility (FTBF).
- The experiment is foreseen as taking place in several phases
  - *Phase I* renovate the ArgoNeuT cryostat&TPC and add a new cryogenics system, new cold electronics, new scintillation light read-out and new DAQ.
  - *Phase II* will re-use the cryogenics system and add a new cryostat&TPC. ***New innovative solutions are being considered.***

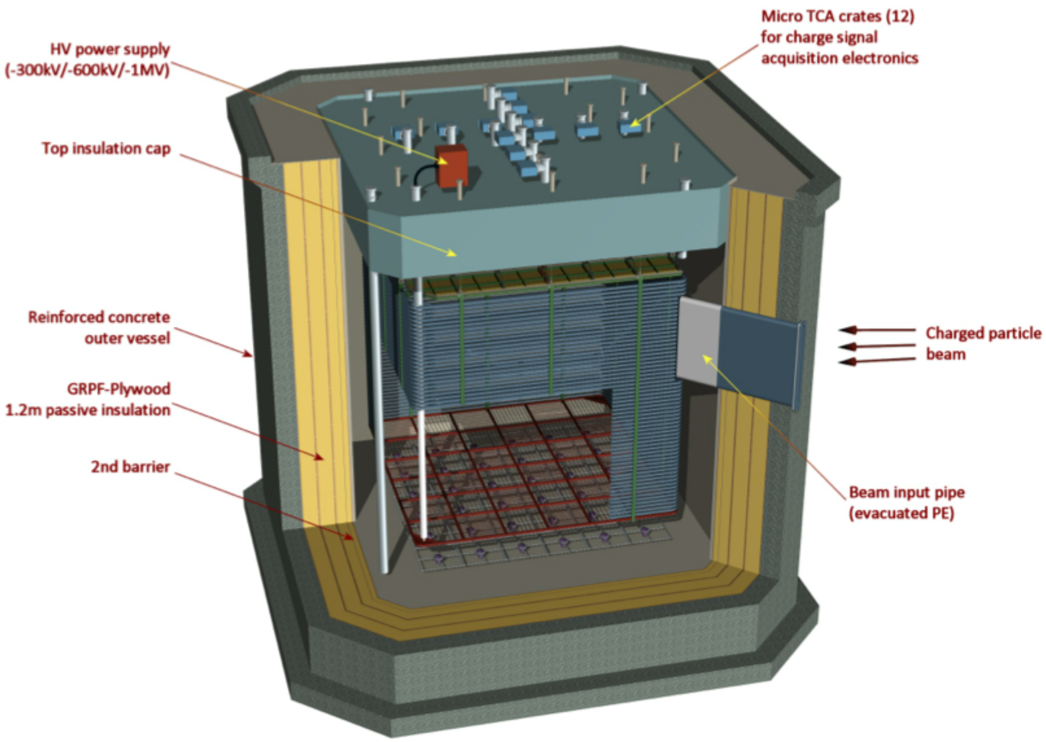


FROM THE RESUMED MCENTRAL BEAM-LINE AT FTBF, A DEDICATED TERTIARY BEAM LINE HAS BEEN DESIGNED, INSTALLED AND IS NOW READY TO OPERATE

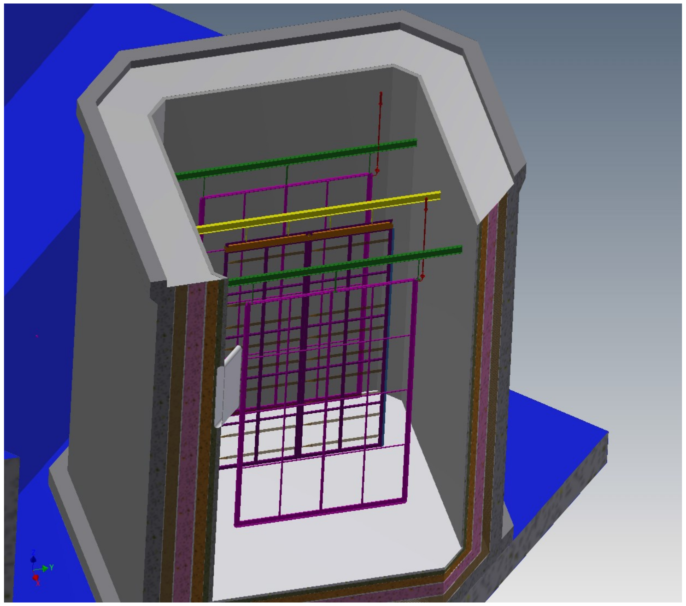
- *Phase I* should take data starting in 2014
- *Phase II* could take data starting in ≥ 2016

WA105 (another potential test beam experiment)

-(Dual phase) LArTPC LBNO demonstrator in the test beam at CERN.



LBNE-relater test: two anode plane assemblies placed in the center of the cryostat and cathode planes near the sides



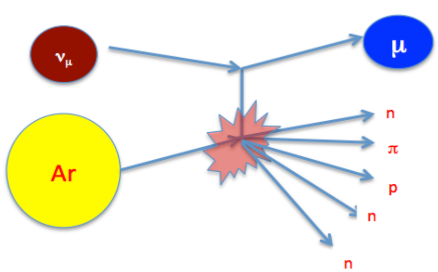
-WA105 Complementarity to LArIAT:

- Potential comparison of dual LArTPC (LBNO baseline) to LBNE single phase LArTPC with test beam data.
- Provide further engagement of Europeans with LBNE(F) – "Internationalization" component.
- Supported by CERN.

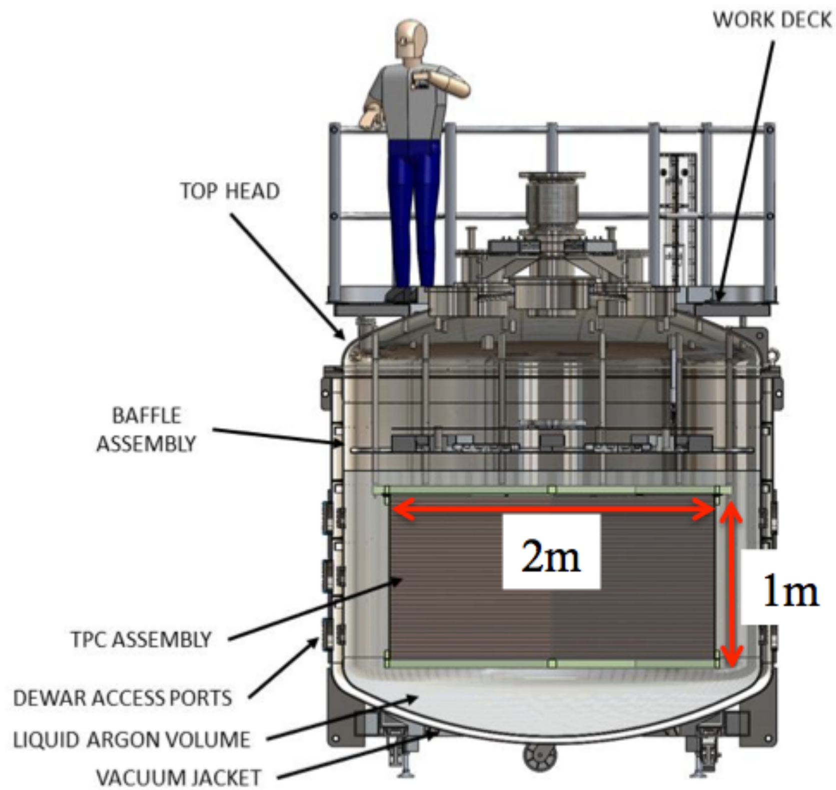
CAPTAIN

CAPTAIN: Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

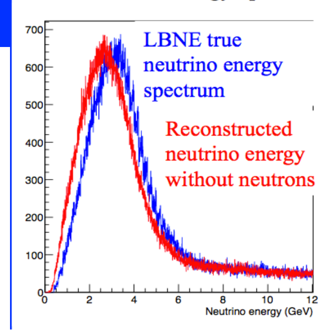
- CAPTAIN Detector
  - hexagonal TPC with 1m vertical drift, 1m apothem, 2000 channels, 3mm pitch, 5 instrumented tons
  - cryostat 7700 liter capacity, evacuable, portable, operable safely at multiple locations
  - all cryogenic connections made through top head
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - using same cold electronics and electronics chain as MicroBooNE (front end same as LBNE)
- CAPTAIN prototype
  - Hexagonal TPC with 30 cm drift, 50cm apothem, 1000 channels, 3mm pitch, 400 instrumented kilograms
- Physics program focused on challenges to LBNE low-energy neutrino (supernova) and medium-energy neutrino (long-baseline and atmospheric) programs



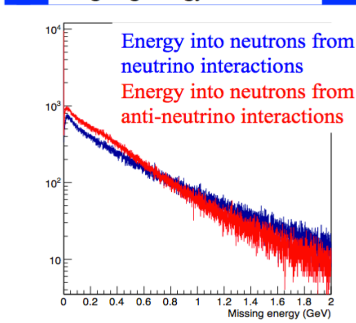
From C. Mauger



LBNE Neutrino Energy Spectrum

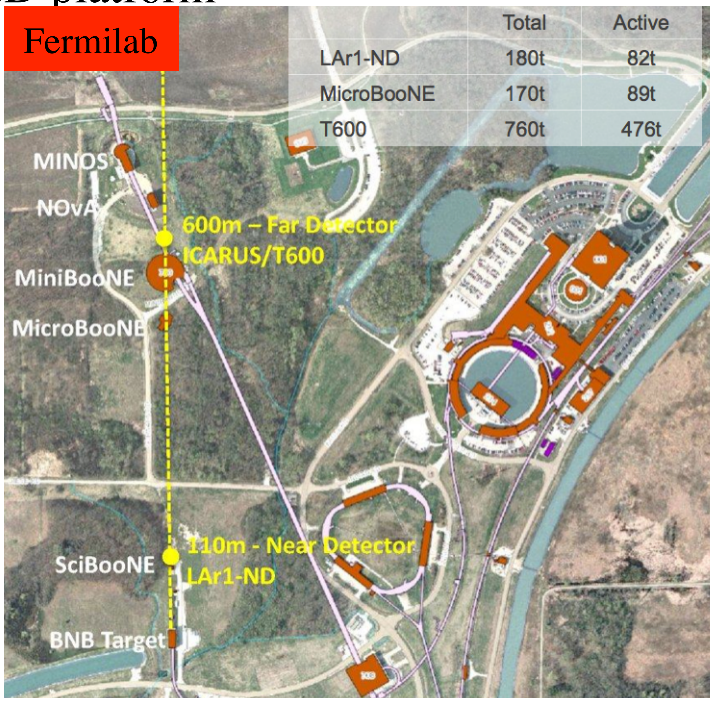


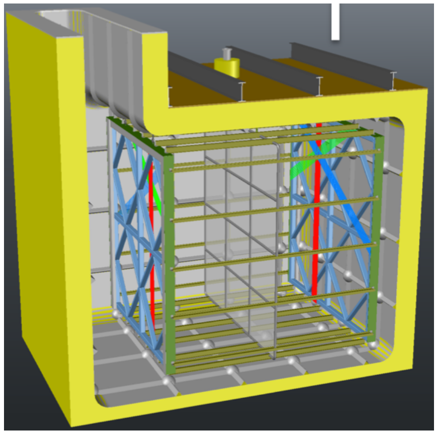
Outgoing energy in neutrons

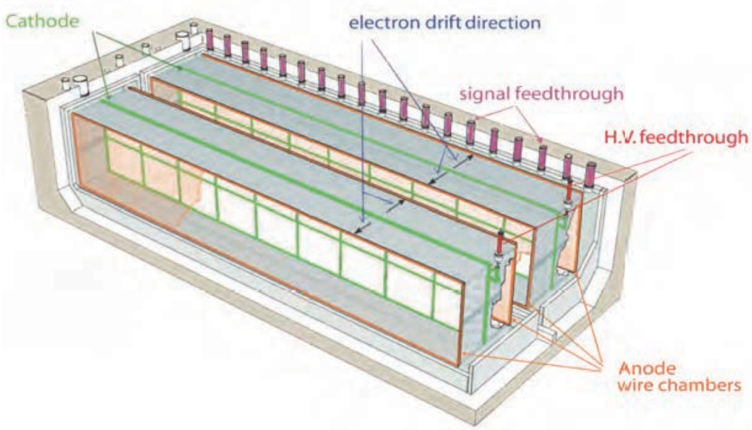


Short-baseline Neutrino Experiments

- Testing Neutrino Anomalies with Multiple LAr TPC Detectors at Fermilab
- Short baseline program will be coordinated to serve as R&D platform
  - -Automated event reconstruction
  - -Laser Calibration
  - -Photon detector R&D
  - -TPC readout
  - -Cold/warm electronics
  - -Cold feed-throughs/understanding of HV breakdown
  - -Argon purification
  - -Cryogenic liquid processing
  - -…

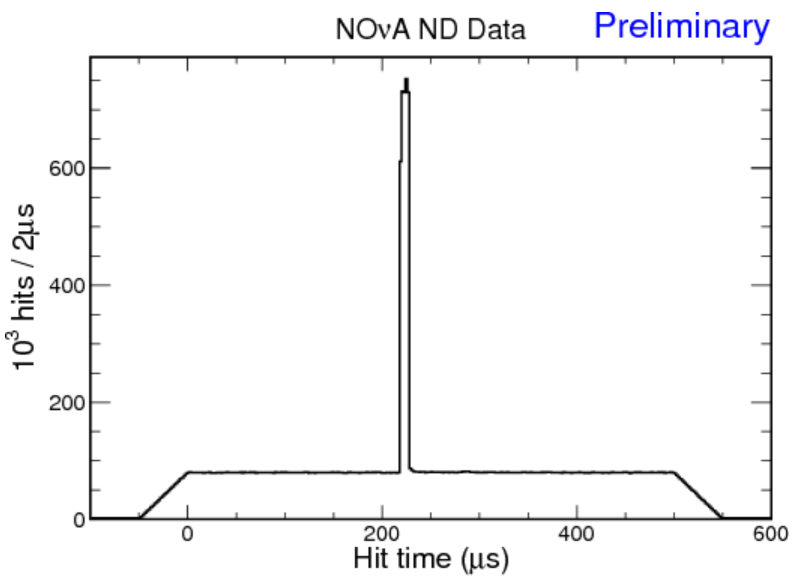


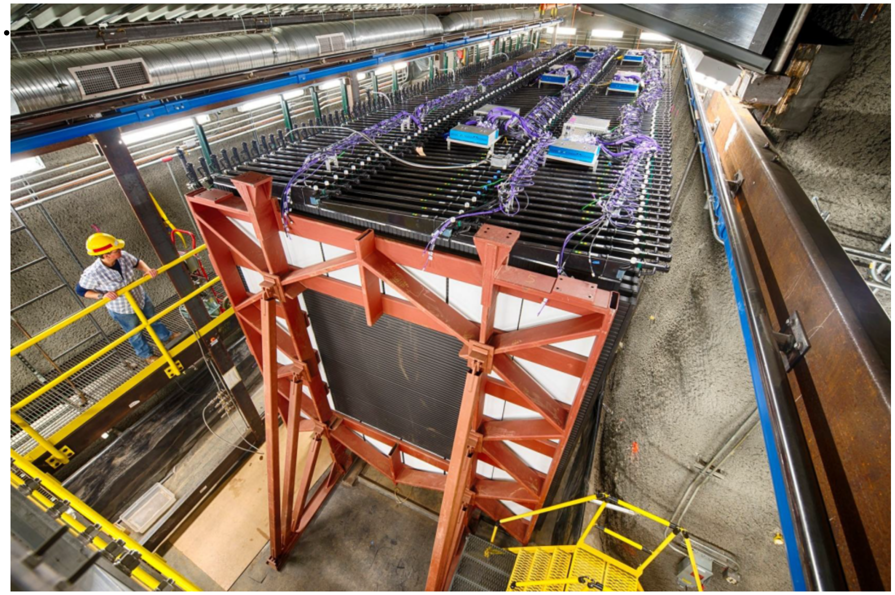


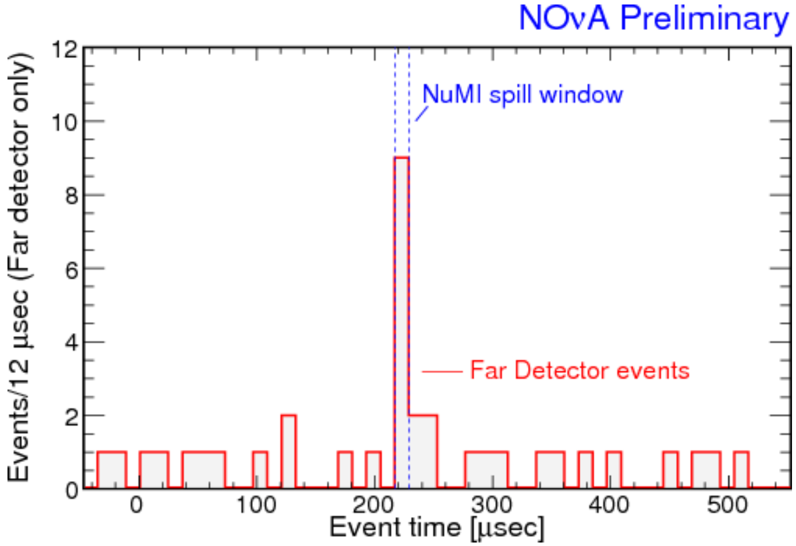


Other Long-Baseline Neutrino Experiments: NOνA

- NOνA Detectors are complete and taking data.

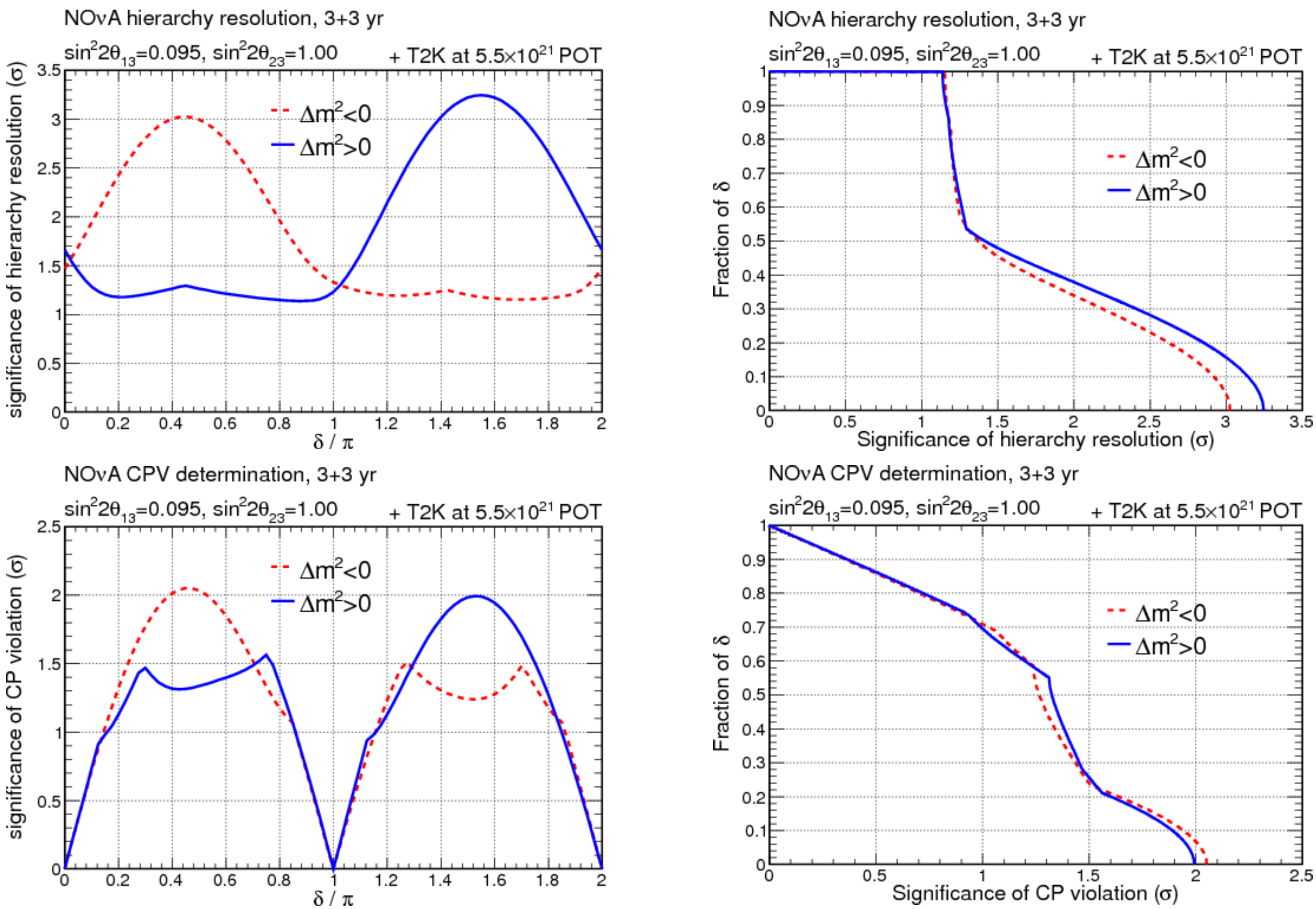






Other Long-Baseline Neutrino Experiments: NOνA

- NOνA Mass Hierarchy and CP-violation Sensitivities (combined with T2K).



- NOνA just started and important results will start coming soon.

Conclusions

- Scientific motivation and scale of the next generation long-baseline neutrino oscillation experiment is well-known. LBNE design meets the requirements for a comprehensive experiment with the potential to make fundamental discoveries in the areas of leptonic CP violation, neutrino masses, proton decay, and supernova neutrinos.

- An international Long-Baseline Neutrino Experiment hosted at Fermilab will deliver the essential components of this project:
  - -A high intensity neutrino beam
  - -A high resolution near detector system
  - -A liquid argon underground Far Detector with at least 34 kton fiducial mass

- The U.S. P5 committee has recommended that the development of an international long-baseline neutrino facility, hosted by the U.S., be a top priority.

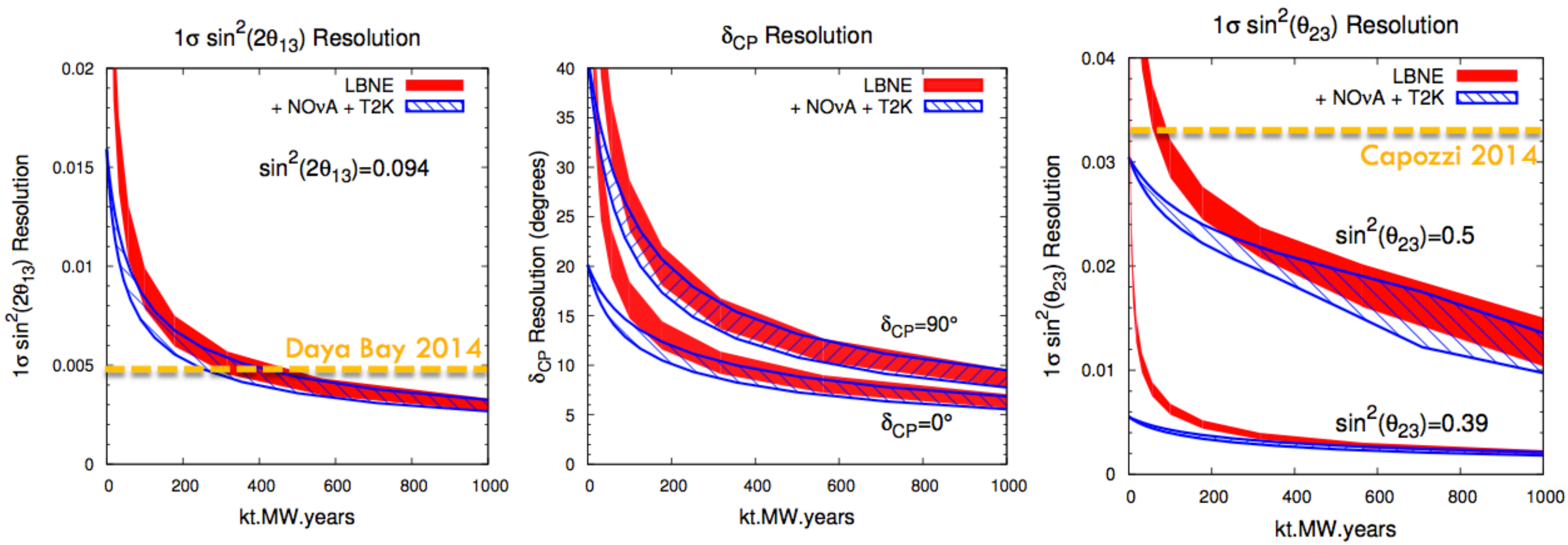
- A series of meetings with government agencies, (inter)national laboratories, and researchers is being organized to fully internationalize the design, funding, construction and operation of the facility.

- We hope the world-wide neutrino community will come together to realize this exciting program.

Backup Slides

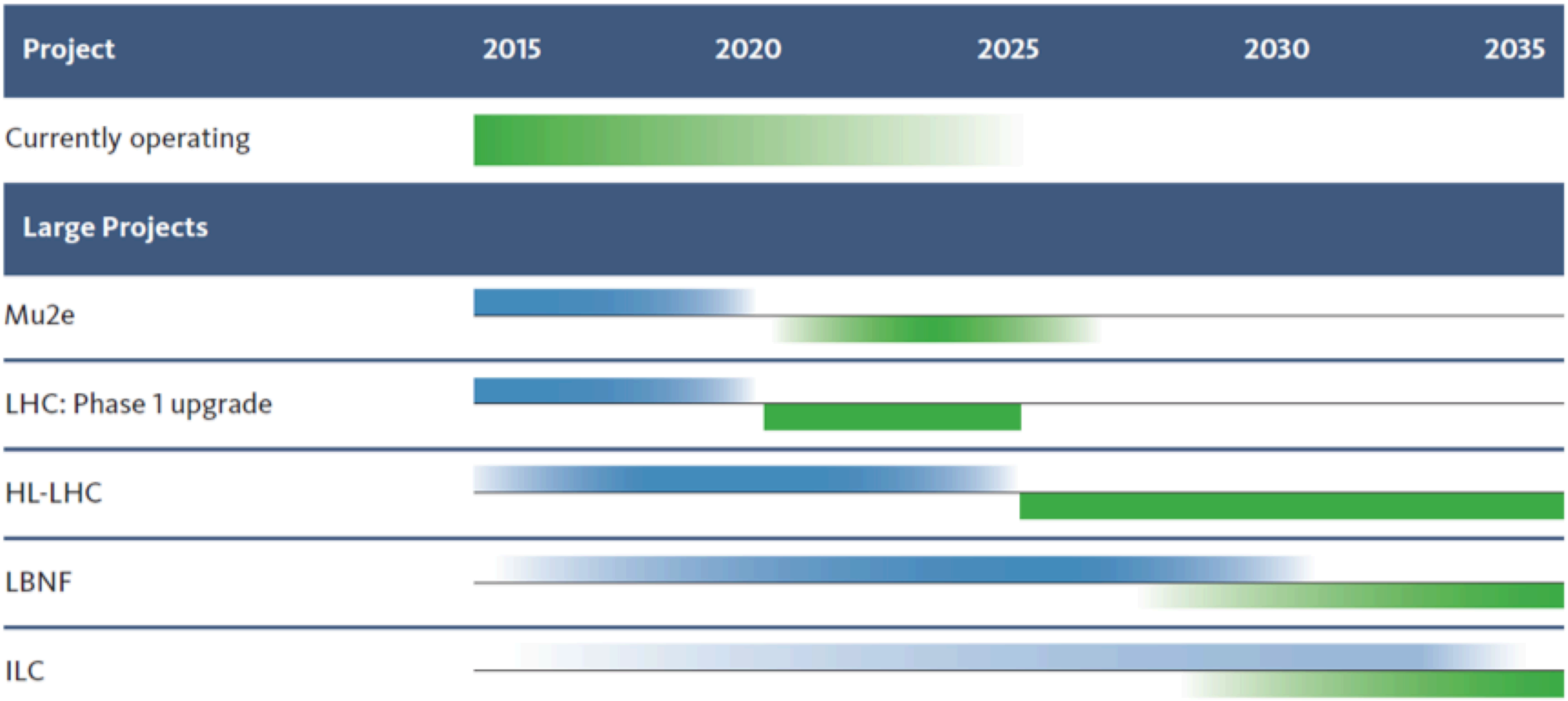
LBNE Precision

- Precision measurement of neutrino oscillation parameters in a single experiment



P5 Timeline

-Timeline as presented in P5 report.



Plausible Timeline for a Phased International Program

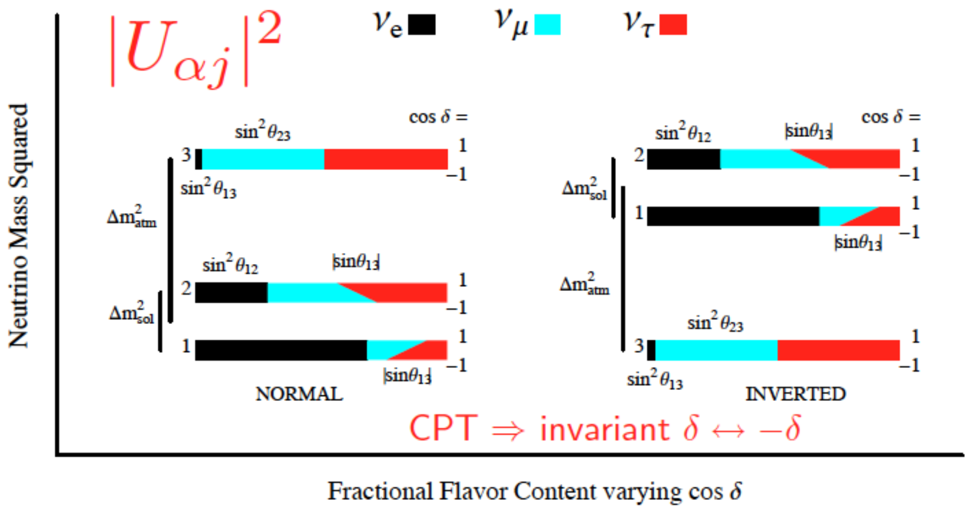
- 2025-2030
  Detector mass: 15 kt (fid.)
  Proton beam power: 1.2 MW
  =>Exposure: 90 kt.MW.yr

- 2030-2035
  Add 20 kt = 35 kt
  Proton beam power: 2.3 MW
  =>Total Exposure: 490 kt.MW.yr

- P5 report recommends the following minimum requirements:
  120 kt*MW*yr by 2035 ⇒ 10-12 kt undergrounds w/ 1.2 MW beam

- The report recommends to plan for a cavern to accommodate 40 kt fiducial mass and set as a goal 600 kt*MW*yr exposure

Major Physics Goal



- Is CP invariance violated in neutrino oscillations ? ($\delta \neq 0, \pi$)
- What is the neutrino mass hierarchy ? ($\Delta m^2_{31} > 0$?)
- Is ν_3 more ν_μ or ν_τ ? ($\theta_{23} = \pi/4$?)

$$\delta m^2_{sol} = +7.6 \times 10^{-5}\ eV^2$$

$$|\delta m^2_{atm}| = 2.4 \times 10^{-3}\ eV^2$$

$$|\delta m^2_{sol}|/|\delta m^2_{atm}| \approx 0.03$$

$$\sin^2\theta_{12} \sim \frac{1}{3}$$

$$\sin^2\theta_{23} \sim \frac{1}{2}$$

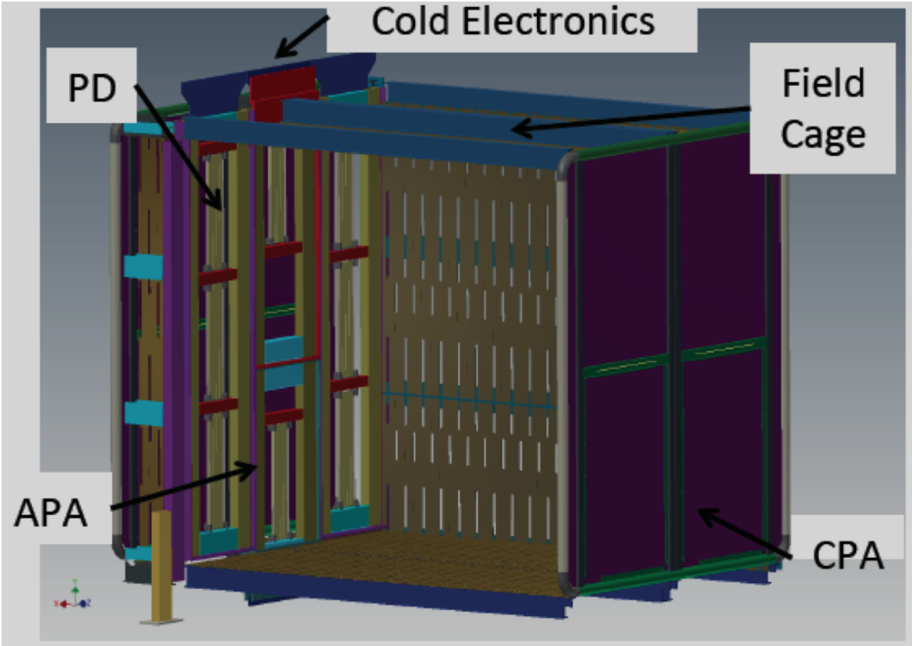
$$\sin^2\theta_{13} \sim 0.02$$

$$0 \leq \delta < 2\pi$$

Is this picture consistent and complete ?

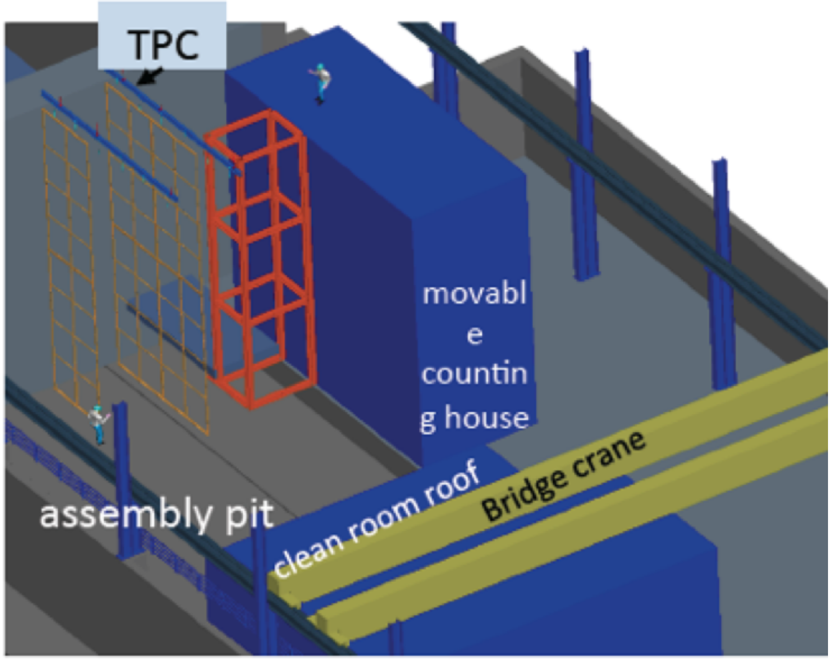
Far Detector Prototyping

- 35-t scale LAr TPC Prototype
  - -Test membrane technology
  - -Cryo-system design
  - -Cryogenic commissioning underway
  - -Install a TPC prototype in 2015
  - -Will be taking cosmic ray data 2015

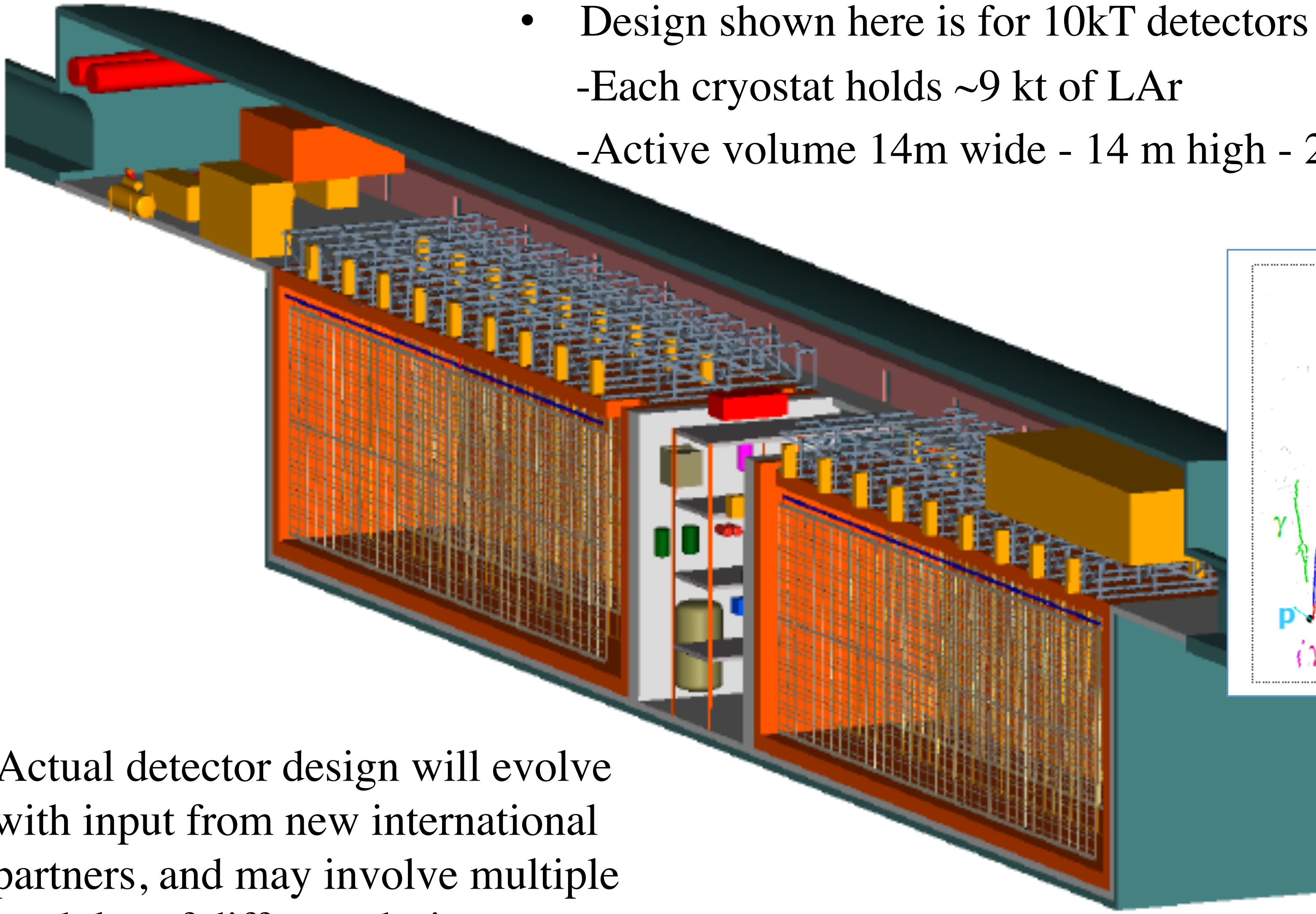


- Full scale warm prototype
  - -Will start construction in 1 year
  - -Full scale TPC module construction
  - -To be installed at Fermilab

- Short baseline program will be coordinated to serve as R&D platform



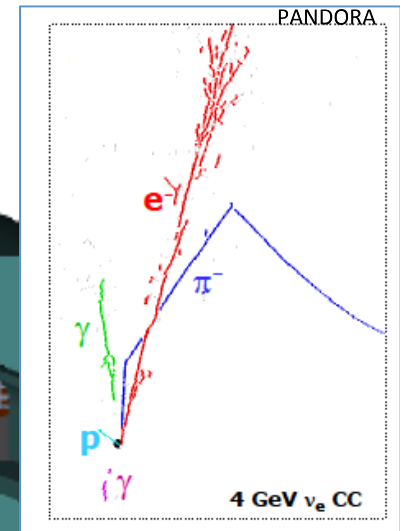
The LBNE Far Detector: 10kt design



- Design shown here is for 10kT detectors

  -Each cryostat holds ~9 kt of LAr

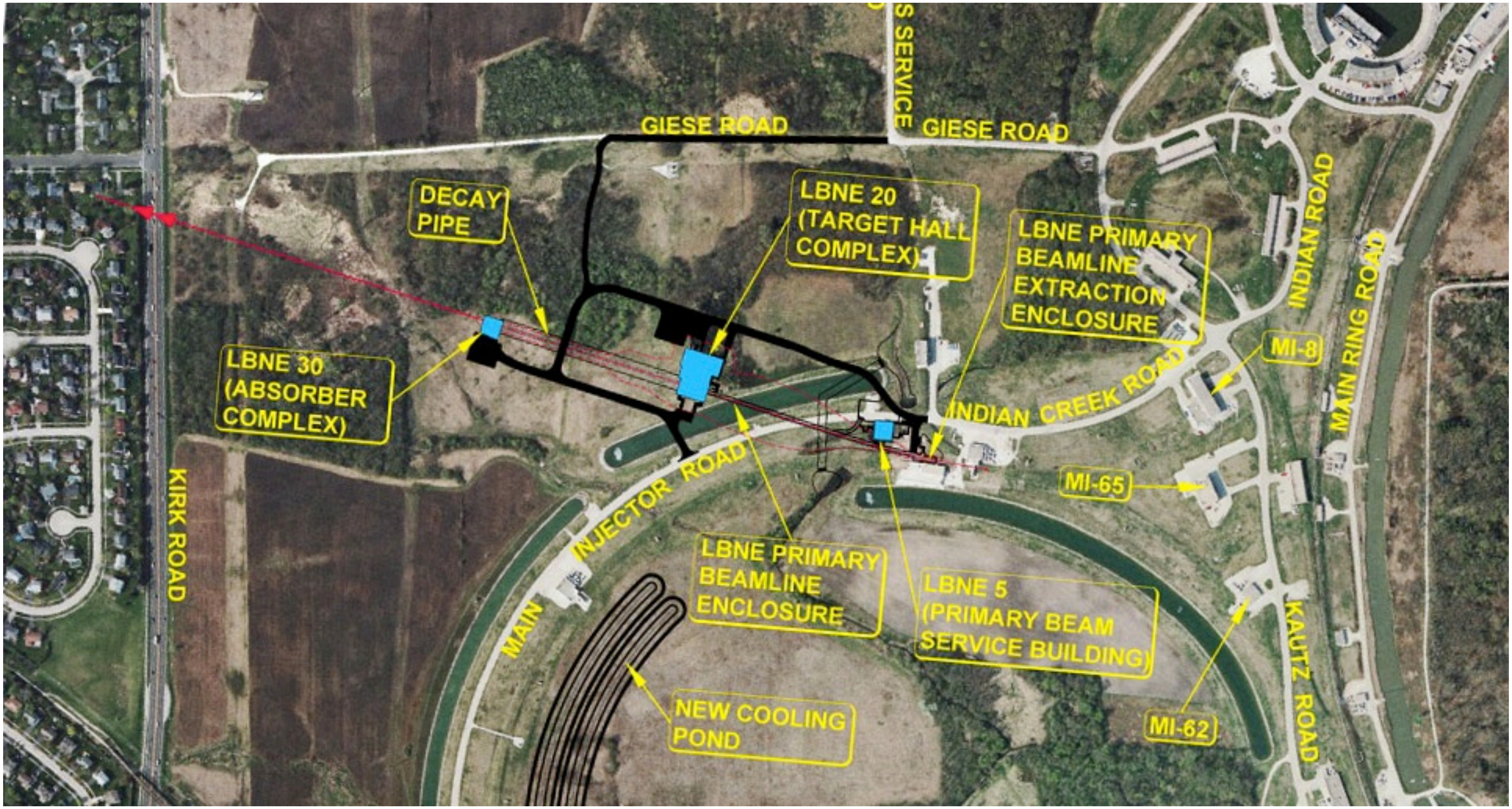
  -Active volume 14m wide - 14 m high - 25.4 m long



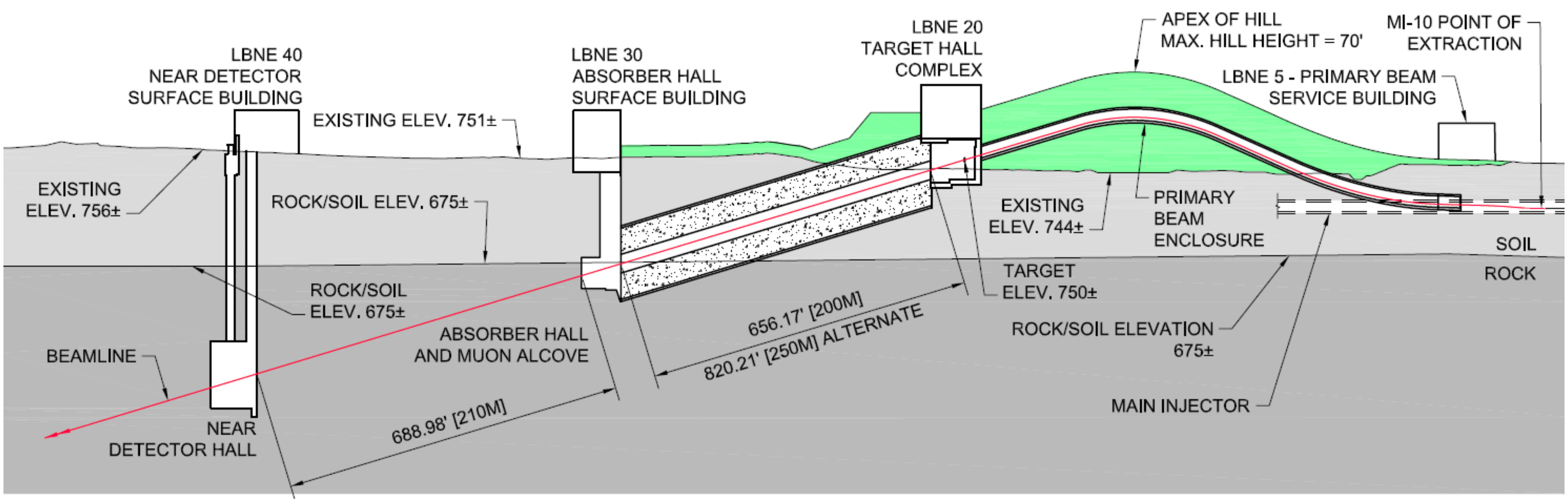
-Actual detector design will evolve with input from new international partners, and may involve multiple modules of different designs.

-Goal is to have ≥ 34 kt fiducial volume ≈ 40kt of liquid argon.

Layout on the Fermilab site

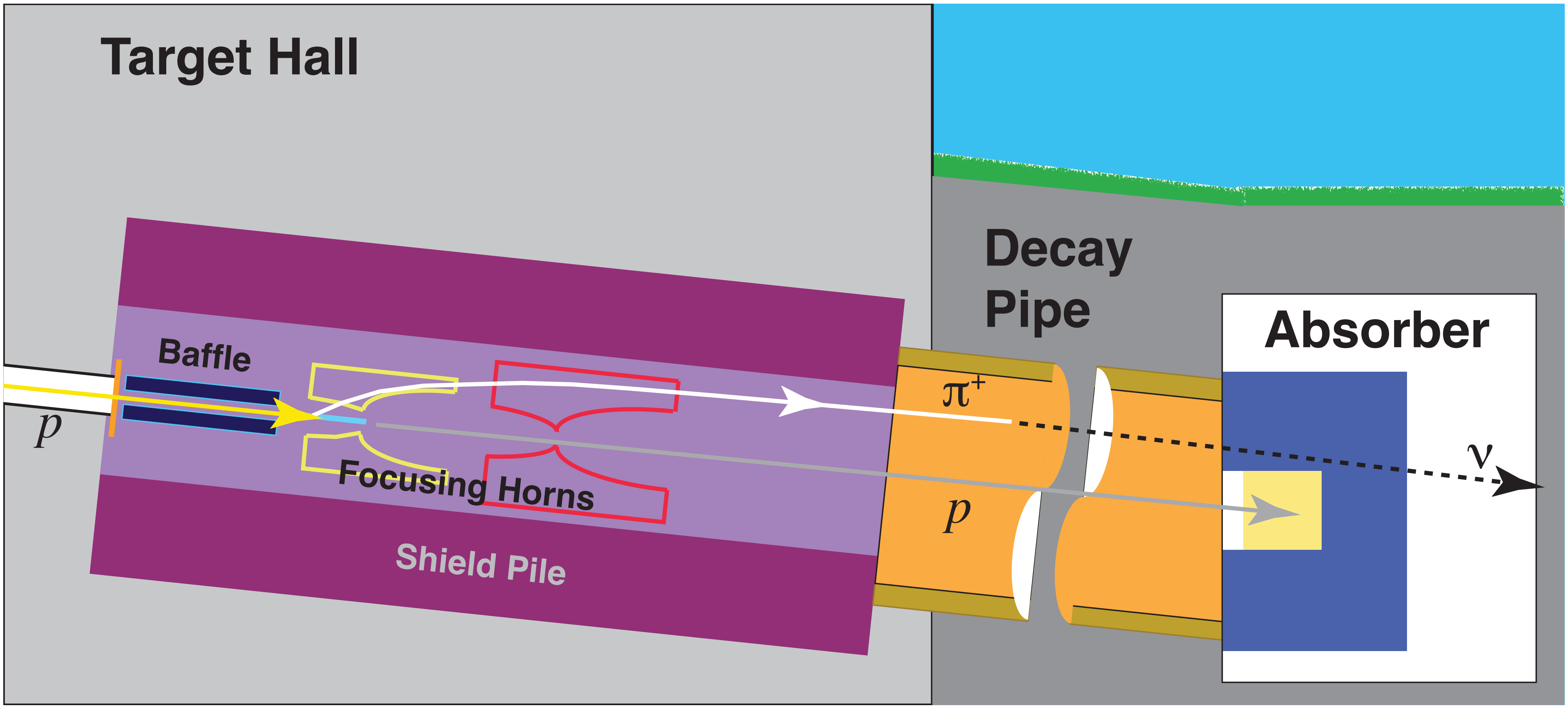


Cross-section of NDS Layout



- Two sets of detector systems:
  - Measure muons after the absorber
  - Measure neutrinos

Layout of LBNE: Neutrino Beam

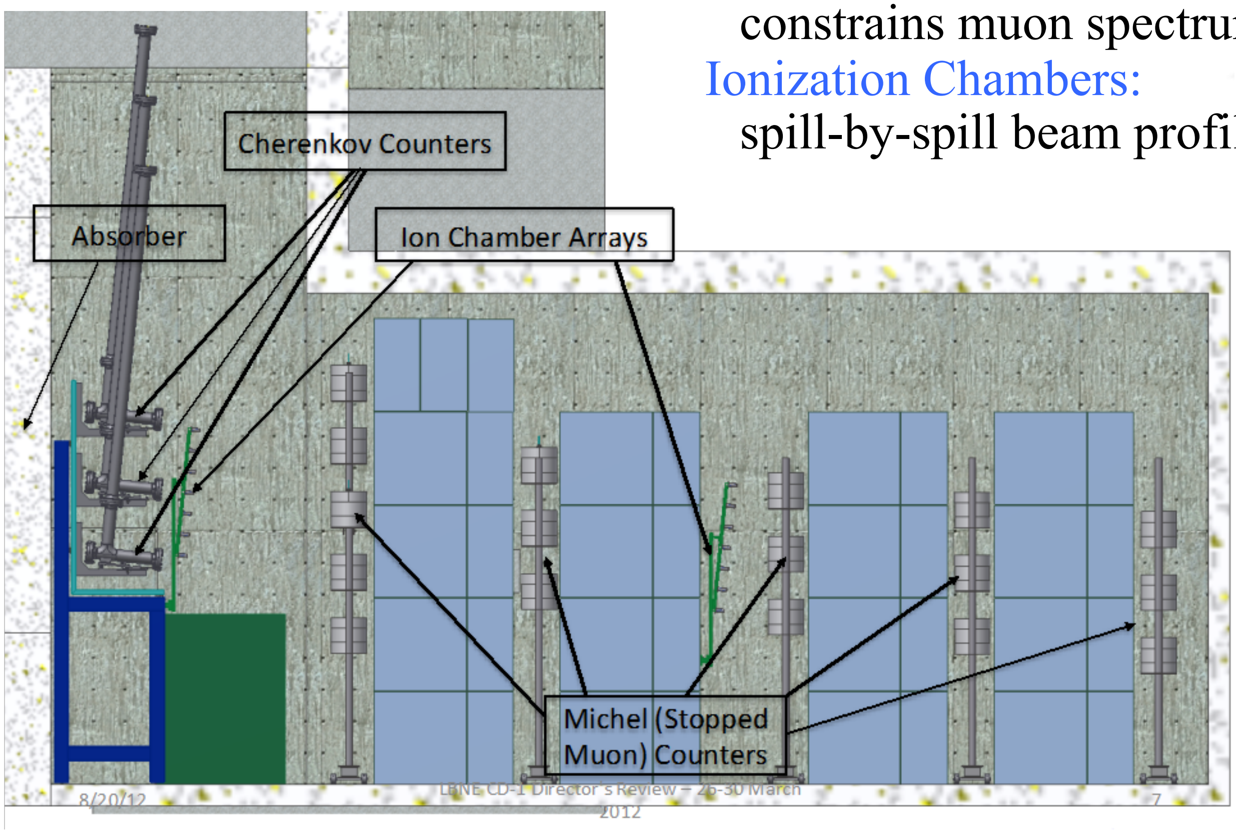


- Conventional neutrino beam from charged pion decay – beam power of 1.2 MW
- All permanent fixtures rated for 2.3 MW operation

Measurements of muons post-absorber

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

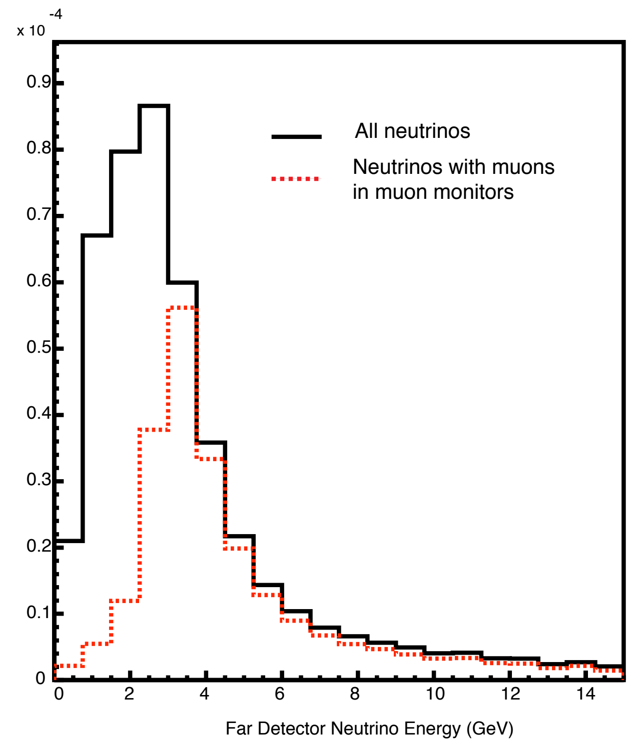
- $E_\nu = (0\text{-}0.43) E_\pi$
- $E_\mu = E_\pi - E_\nu = (0.57\text{-}1.0) E_\pi$



Cherenkov Detectors:
measure all muons above a variable threshold
constrains muon spectrum (correlated with E_ν)

Michel Decay Detectors:
measure muons that stop at a given depth in material
constrains muon spectrum

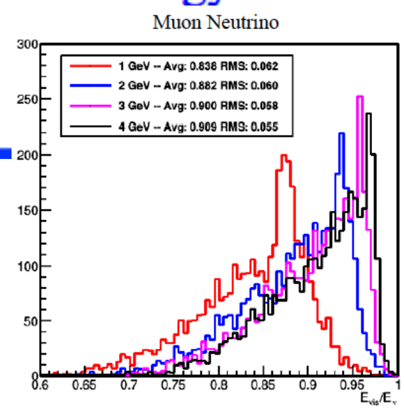
Ionization Chambers:
spill-by-spill beam profile

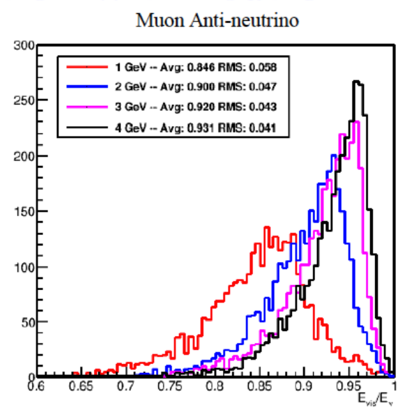


CAPTAIN Physics Program

Neutron Beam
Low-Energy Neutrino Beam
Medium-Energy Neutrino Beam

- Low-energy neutrino physics related
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to ν_e appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
  - Measure inclusive and exclusive channels neutrino CC and NC cross-sections/ event rates in a neutrino beam of appropriate energy
  - Test methodologies of total neutrino energy reconstruction with neutron reconstruction





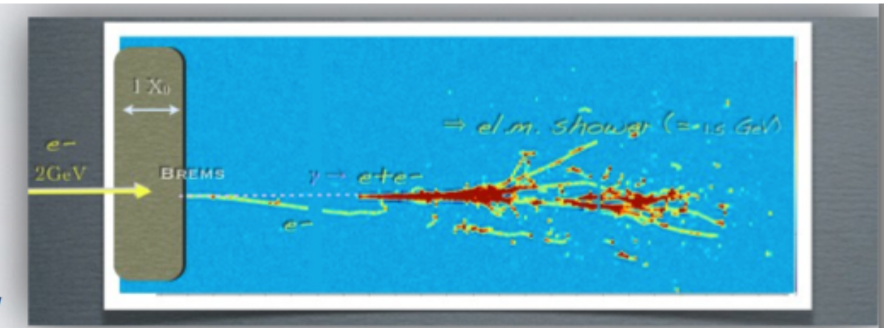
LArIAT

SCIENCE:

ELECTRON VS PHOTON SHOWER DISCRIMINATION

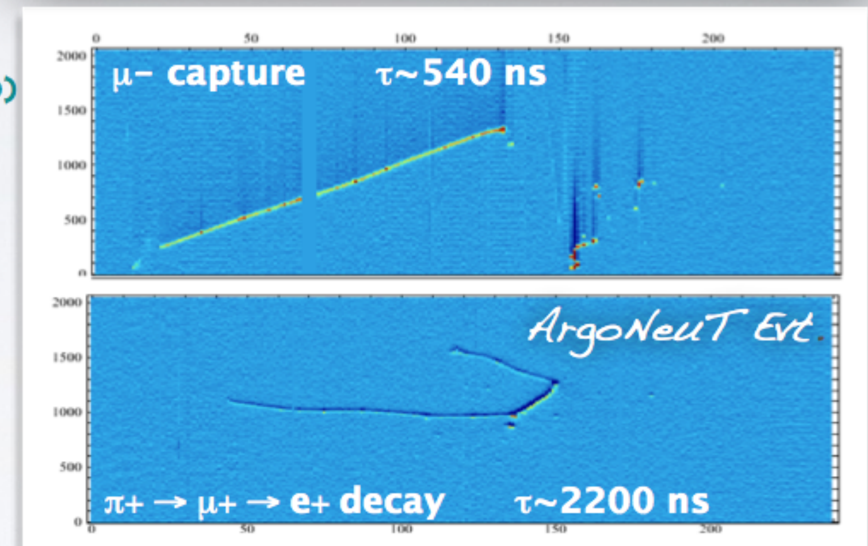
Experimental confirmation for the separation efficiencies (MC determined) - key feature of LArTPC technology

Enable ultimate development and most reliable separation criteria/ algorithms in off-line reconstruction codes



MUON SIGN DETERMINATION (W/OUT MAGNETIC FIELD)

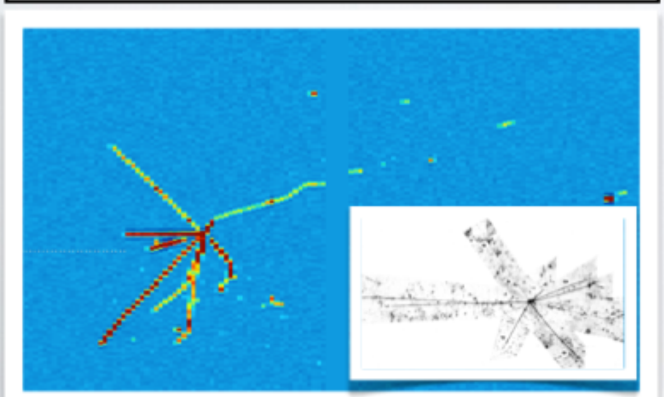
Explore a LArTPC feature never systematically considered (decay vs capture in LAr)



STUDY OF NUCLEAR EFFECTS

Pion Absorption, π^0 from $\pi^\pm$ Charge Exchange
Kaon interaction channels and
Antiproton annihilation (relevant for n-nbar oscillations)

Simulation of Antiproton Star in LAr



DEVELOPMENT OF A NEW CONCEPT IN LAR SCINTILLATION LIGHT COLLECTION

Relate energy deposited
to charge and light
for an improved calorimetric energy resolution